Fishery Resources and Habitats in a Headwater Lake of the Brock River, NT, 2003-2005

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by

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A headwater lake of the Brock River, hereafter called "Brock Lake", provides habitat for populations of Arctic Charr (*Salvelinus alpinus*), Lake Trout (*Salvelinus namaycush*) and Slimy Sculpin (*Cottus cognatus*). Brock Lake is located above the Arctic Circle within Tuktut Nogait National Park, Northwest Territories (NT), Canada. The community of Paulatuk, NT requested the present study, the purpose of which was to assess the habitats and fish community in the lake, provide information for the eventual assessment of the potential for a subsistence fishery in this location, and to obtain baseline information on Arctic Charr and their life history. The study involved sampling during a winter subsistence fishery at Brock Lake in November 2003, and a physical, chemical and biological assessment of the lake in July 2004 and 2005. Similar to other arctic lake ecosystems, the lake is highly oligotrophic and the Brock Lake food web appears to be driven mainly by benthic productivity. Physically, the lake is characterized by its small size (2.5 km^2), a large littoral habitat (as indicated by a larger perimeter to area ratio), and the presence of small and patchy profundal areas ($\geq$ 20 m deep) representing 18% of total lake volume. We hypothesized that these physical features may facilitate the co-occurrence of Arctic Charr and Lake Trout in Brock Lake, by permitting transient or seasonal habitat segregation of these species between profundal and littoral niches. Anadromous and resident Arctic Charr co-occur in the lake. The Brock Lake system serves as an over-wintering area for anadromous Arctic Charr and is likely used for spawning and rearing as well. The degree of anadromy in the Arctic Charr population appeared to be high, with all (100%) specimens harvested during winter being anadromous. Low Arctic Charr CPUE in both winter and summer indicated that the population is small. A small population size and high degree of anadromy may be related to low lake productivity, a small profundal habitat, and the presence of Lake Trout. Results of otolith microchemistry analyses demonstrated a similar age-at-first-migration and reproductive strategy (i.e., co-occurrence of specimens that migrate and do not migrate to sea during the year that they spawn) in Arctic Charr from Brock Lake compared to Arctic Charr from the Hornaday River. This provides additional support for earlier evidence (from tag return information) that Arctic Charr from these systems may belong to the same anadromous population. In July, Lake Trout abundance as CPUE was relatively high (at approx. 1 fish per net hour) compared to similar-sized lakes in the Yukon Territory.

Key words: Arctic Charr; Lake Trout; arctic lakes; otolith microchemistry; life-history types; degree of anadromy; CPUE; fish habitat.

RÉSUMÉ

Roux, M.-J., Harwood, L. A., Illasiak, J., Babaluk, J.A., and de Graff, N. 2011. Fishery resources and habitats in a headwater lake of the Brock River, NT, 2003-2005. Can. Manuscr. Rep. Fish. Aquat. Sci. 2932: viii + 61 p.

Un lac tributaire de la rivière Brock, ci-après dénommé « lac Brock », fournit un habitat pour les populations d'omble chevalier (*Salvelinus alpinus*), de touladi (*Salvelinus namaycush*) et de chabot visqueux (*Cottus cognatus*). Le lac Brock est situé au-dessus du cercle polaire arctique, dans le parc national Tuktut Nogait, dans les Territoires du Nord-Ouest (NT), au Canada. La communauté de Paulatuk, NT, a commandé la présente étude, dont le but était d'évaluer les habitats et les communautés de poissons dans le lac, fournier l'information pour l'évaluation finalement de la possibilité d'une pêche de subsistance à cet endroit et l'obtention de renseignements de base sur l'omble chevalier et leur cycle biologique. L'étude a porté sur l'échantillonnage au cours d'une pêche de subsistance d'hiver au lac Brock en novembre 2003, et sur une évaluation physique, chimique et biologique du lac en juillet 2004 et 2005. Tout comme d'autres écosystèmes lacustres de l'Arctique, le lac est très oligotrophe et le réseau trophique du lac Brock semble être alimenté principalement par la productivité benthique. Physiquement, le lac se caractérise par sa petite taille (2,5 km^2), un vaste habitat du littoral (comme l'indique le rapport plus large du périmètre à la surface), et la présence de petites zones inégales et profondes ($\geq$ 20 m de profondeur), représentant 18 % du volume total du lac. Nous avons présumé que ces caractéristiques physiques peuvent faciliter la cooccurrence de l'omble chevalier et du touladi dans le lac Brock, en permettant la ségrégation transitoire ou saisonnière de l'habitat de ces espèces entre les niches de zones profondes et du littoral. Les ombles chevaliers anadromes et résidents coexistent simultanément dans le lac. Le système du lac Brock sert de zone d'hivernage pour l'omble chevalier anadrome et probablement est utilisé aussi pour le frai et l'élevage. Le niveau d'anadromie dans la population d'omble chevalier semblait haut, tous les spécimens (100 %) pêchés au cours de l'hiver étant anadromes. De faibles prises par unité d'effort (PPUE) d'omble chevalier, en hiver comme en été, indiquent que la population est petite. Une petite taille de la population et un haut niveau d'anadromie peuvent être liés à une faible productivité du lac, un petit habitat de zones profondes, et la présence du touladi. Les résultats des analyses de microchimie des otolithes ont démontré un même âge à la première migration et une stratégie similaire en matière de reproduction (c.-à-d., cooccurrence de spécimens qui migrent, et ne migrent pas vers la mer au cours de l'année où ils se reproduisent) chez l'omble chevalier du lac Brock par rapport à l'omble chevalier de la rivière Hornaday. Il s'agit d'un appui supplémentaire aux éléments de preuve précédents (obtenus à partir de l'information sur le taux de retour des étiquettes) confirmant que l'omble chevalier provenant de ces systèmes peut appartenir à la même population de poissons anadromes. En juillet, le touladi était abondant, puisque la PPUE était relativement élevée (environ 1 poisson par heure nette) par rapport à celles des lacs de taille similaire dans le territoire du Yukon.

Mots clés: omble chevalier; touladi; lacs de l'Arctique; otolithe; microchimie; types de cycle biologique; niveau d'anadromie; PPUE; habitat du poisson.

INTRODUCTION

The Arctic Charr (*Salvelinus alpinus*) of the Hornaday River are an important subsistence resource for the people of Paulatuk, Northwest Territories, Canada (Fig. 1). Arctic Charr harvests in the Paulatuk area are managed according to the community's Charr Management Plan, which includes a harvest guideline for total catch as well as a closed area (Department of Fisheries and Oceans 1999; Paulatuk Hunters and Trappers Committee 2003). Sampling of the harvested fish suggested a downward trend in the status of the Hornaday River Arctic Charr stock starting in 2003, without full recovery by 2007 (Harwood 2009). Voluntary fishing restrictions (Paulatuk Hunters and Trappers Committee 2003) were put in place beginning in 1999 and these continue to the present day. For this reason, the community has been actively seeking other locations to fish for Arctic Charr and other species, mainly for a winter supply of fish. One such location that has been considered is the headwater lake of the Brock River, known locally and hereafter referred in this report as Brock Lake. The lake is located within the Melville Hills region of Tuktut Nogait National Park, at a straight-line distance of 95 km ENE of Paulatuk (Fig. 1). Brock Lake is known to support unexploited populations of Arctic Charr and Lake Trout.

Arctic Charr in Brock Lake were thought to be resident, non-anadromous fish. However, the capture of an Arctic Charr in the lake in winter 2000 that had been tagged in late-August the previous year at the mouth of the Hornaday River (see Fig. 1) demonstrated: (1) the presence of anadromous Arctic Charr in Brock Lake and (2) the movement of Arctic Charr from Brock Lake into Darnley Bay and the lower reaches of the Hornaday River. This finding raised the question about fishing for Brock Lake Arctic Charr as an alternate source to Hornaday River Arctic Charr, as the two may not be distinct populations. Thus, this study of Brock Lake was undertaken to determine if the lake is being utilized on a regular basis by over-wintering Arctic Charr from the Hornaday River population.

The specific objectives of the present study were to: (1) provide information for the eventual evaluation of Brock Lake as a possible alternative subsistence fishery for the people of Paulatuk, (2) provide a basic inventory of fishery resources, lower trophic levels and habitats in Brock Lake, (3) evaluate the occurrence of movements of Arctic

Charr between Brock Lake and the Hornaday River system, and (4) provide additional knowledge to support and implement the Hornaday Charr Management Plan 2003-2005 (Paulatuk Hunters and Trappers Committee 2003).

This project was part of a series of Arctic Charr and Arctic Charr habitat-related projects in the Paulatuk area, coordinated by Fisheries and Oceans Canada (DFO) on behalf of the Canada-Inuvialuit Fisheries Joint Management Committee (FJMC) and Parks Canada. These include ongoing enumeration and sampling of Arctic Charr harvested from the Hornaday River during the late summer upstream migration, monitoring water quality and quantity of the Hornaday River, and implementation of the Paulatuk Charr Management Plan (Paulatuk Hunters and Trappers Committee 2003).

MATERIALS AND METHODS

STUDY AREA

Brock Lake is a pristine, small (248 ha), and relatively shallow (mean depth 10 m) lake located north of the Arctic Circle (69°26'N, 121°41' W) in the Melville Hills region of Tuktut Nogait National Park, Northwest Territories. It is located at an altitude of 390 m above sea level and a straight-line distance of 95 km ENE of Paulatuk (Fig. 1). The length of the Brock River from the main outlet of Brock Lake to its mouth in Darnley Bay is approximately 94 km (Fig. 1). There are no known physical barriers like waterfalls to fish movements on the Brock River, although surface flows in some portions of the river may be non-existent during late summer. The Brock Lake system also includes a second, elongated lake located north-west of Brock Lake (Fig. 2). This lake is locally referred to as Long Lake. Long Lake feeds into Brock Lake via an approximately 1.5 km long stream that has no known natural barriers that would prevent fish movement between the two lakes. However, low water levels may preclude fish movement during late summer. Unlike Brock Lake, Long Lake is not known to have been a historic subsistence fishing site.

Brock Lake is surrounded by arctic tundra (barren) type vegetation and is located in the southern arctic ecozone and Tundra Hills natural region of Canada. The Tuktuk Nogait

National Park is influenced by a low arctic eco-climate consisting of long, cold winters and short, cool summers, with little overall precipitation (Parks Canada 2009). Average seasonal temperatures range from a mean of 5°C in summer and a mean of -26°C in winter (Parks Canada 2009). The geology of the north and central areas of the Park consist mainly of sedimentary rock composed of marine strata (Parks Canada 2009). Community residents can only access Brock Lake by snowmobile (approximately 8 hr from Paulatuk) in winter, or by float plane or helicopter in summer. The presence of human artefacts such as anchor rocks and campsites suggest past usage of the lake's resources.

SAMPLING

Sampling of the biological resources, and physical and chemical characteristics of Brock Lake was conducted over a three-year period. A winter subsistence fishery was sampled during November 13-19, 2003. A bathymetric, limnological and experimental fish survey was conducted between July 16 and July 23 of 2004 and 2005. Field work was led and conducted by Inuvialuit technicians in 2003 and 2005, and a biologist contracted by DFO in 2004.

PHYSICAL AND CHEMICAL CHARACTERISTICS OF BROCK LAKE

Brock Lake was sampled for depth, water quality and substrate type in July 2004. The bathymetric survey of the lake consisted of 1,139 depth measurements made over 84 depth sounding transects using a Garmin 160 depth sounder and transducer mounted on a 15.1 m inflatable boat. Depth measurements were recorded along each transect at intervals of 25 m on average (minimum and maximum distances between depth measurements of 2 m and 47 m). Depth sounding data were used to produce a bathymetric map of the lake using ArcView (ESRI 2004), and to compute total lake volume by summing individual depth contour volumes estimated as:

$$V = 1/3 * H * (A_1 + A_2 + \sqrt{A_1 * A_2})$$

where: V = volume of water for a particular depth contour

H = difference in depth between successive depth contours

A_1 = area of the outer depth contour considered
A_2 = area of the depth contour considered.

Visual observations of the bottom substrate were made over each of the 84 depth sounding transects and recorded to provide qualitative benchmark information. Other lake morphometrics (i.e., surface area, shoreline length and elevation) were calculated using ArcView (ESRI 2004).

Water quality measurements (Secchi depth, pH, conductivity, dissolved oxygen, water temperature and salinity) were made and averaged from seven different stations on the lake using a Horiba U-10 water quality profiler (Fig. 3). Measurements were taken at depth intervals of 1 m to 5 m, depending on site.

Water samples were collected at water quality sites no. 1 and 7 (Fig. 3) for the determination of nutrients, organic carbon (dissolved and particulate) and other inorganics (including trace metals) concentrations. Water samples were collected using a Kemmerer bottle suspended at three different depths: 1 m below the surface, 2 m above the bottom and approximately mid-depth. Water samples were analyzed for nutrients, water color, conductivity, pH, turbidity and total dissolved and suspended solids by Taiga Environmental Laboratory (Yellowknife, NT), and for silicates, cations, anions, particulate organic carbon and nitrogen and 34 trace elements by Environment Canada (Burlington, ON). Reported values were averaged by water layer and over the entire water column.

BIOLOGICAL ASSESSMENT

Winter fishery

Harvesters from Paulatuk travelled by snowmobile to Brock Lake and fished for subsistence purposes on November 13-17, 2003. Fishing locations in the lake were chosen following consultations with Paulatuk elders before departing for the field. A total of 11 gillnet sets were made using a 45.7 m long by 2.4 m deep, 114 mm (4.5") monofilament stretched-mesh net, and three different gangs of 140 mm (5.5") monofilament stretched-mesh (each 27.4 m x 1.8 m, 27.4 m x 2.4 m, and 45.7 m x 2.4

m, respectively). Nets were set suspended approximately 1 m under the surface of the ice and 0.5 m above the lake bottom at six different offshore locations (Fig. 4). Ice thickness was approximately 46 cm at the time of fishing. Sets duration ranged from 12-30 hr. Fishing time for all sets totalled 253.6 hr. Harvested fish were dead-sampled for fork length (mm), round weight (g), sex and maturity. Otoliths were removed for age determination and micro-chemistry analysis. Stomach contents were qualitatively examined.

One gillnet set was made in Long Lake (see location on Fig. 2). Harvester's observations were recorded but no quantitative catch or biological information was collected at this location.

Summer surveys

Zooplankton was collected at two sites in July 2004 [water quality sites no. 1 and 2 (Fig. 3)]. Vertical hauls were made through the length of the water column using a Wisconsin-type, 200 μm mesh plankton net. Zooplankton samples were preserved in the field for subsequent analysis. Samples were later sorted, identified to species and counted by North/South Consultants Inc. (Winnipeg, MB).

For summer surveys, fish were caught using experimental multi-mesh gillnets set at approximately 1 km intervals around the lake perimeter (Fig. 4). A total of 61 sets were made between July 17 and 20, 2004, and 60 sets were made between July 16 and 20, 2005. In each year, this corresponded to a survey intensity of approximately 24 sets·km^{-2} of lake surface area. Two gangs of nets that were 55 m (60 yd) long and either 1.8 m or 3.7 m deep were used. Each gang consisted of three 18.3 m (20 yd) panels of 76 mm (3"), 38 mm (1.5") and 64 mm (2.5") multi-filament stretched mesh. Panels were linked together by the float lines and lead lines. The use of small mesh gillnets allows for the non-destructive sampling of Lake Trout which tend to be entangled, rather than wedged, by this kind of gear (Lester 1991). Each net was set for approximately 60 min. Nets were set perpendicular to the lake shoreline and anchored in approximately 1 m of water at the near-shore end. Small (64 mm) and large (76 mm) mesh panels were alternated in being set closest to shore. The depth at which nets were set was recorded in July 2004 and the nets extended out from shore to depths ranging from 2 m to 22 m. Surface water

temperature was recorded at all sets locations in July 2004. All fish captured were identified to species and measured for fork length (mm) and round weight (g). In 2004, Lake Trout mortalities (n = 9) were dead-sampled, identified for sex and maturity, and ageing structures (otoliths) and stomach contents were removed for further analysis. The presence of external and internal parasites was assessed on all mortalities. Fifty Lake Trout and two Arctic Charr (>350 mm) were tagged with yellow, t-bar tags (Floy Tag & Mfg. Inc.) and released in 2004. Tagging was done to assess the distribution and movements of Lake Trout within the lake, and to potentially generate an estimate of Lake Trout population size. Tagging of Arctic Charr was done to assess potential movements of Arctic Charr between Brock Lake and the Hornaday River. In 2005, all fish were released alive except for three Lake Trout mortalities and three Arctic Charr that were sacrificed for stomach contents and otolith strontium analyses. The presence of internal parasites was assessed on all mortalities. A random sample of 20 Lake Trout (>350 mm) was tagged and released in 2005.

In July 2004, minnow traps and a beach seine were used at the lake's main inlet and outlet and at the mouth of a small inflowing stream in the western basin of the lake (Fig. 3). Eight 6.4 mm (1/4") mesh Gee minnow traps baited with salmon roe were set for 15 hr to 25.5 hr. Beach seining consisted of sweeping an area of 100 m^2 to 260 m^2 with a 5 m long oval seine made of 3.2 mm (1/8") nylon mesh. Fish caught by seine and in minnow traps were identified to species, counted, and measured for total or fork length (mm) when possible. Angling was performed at the lake's main inlet and outlet in 2004. Angled fish were identified to species, measured for fork length (when practical) and released alive.

LABORATORY ANALYSES

Arctic Charr ages were estimated at the Fisheries and Oceans Canada, Arctic Fish Ageing Laboratory in Winnipeg using the otolith thin-section method described in Reist et al. (1995). Lake Trout ages were estimated by an independent contractor using the whole otolith method described in Nordeng (1961). Note that this method has been shown to underestimate ages, relative to the section method, for larger (i.e., older) specimens of species closely related to Lake Trout (e.g., Arctic Charr, see Barber and McFarlane 1987). Power (1978), while not stating it directly, implied that this was the

case for Lake Trout, too. Lake Trout ages presented in this report, while comparable between the years of our study, should be viewed with caution as they may not be representative of the actual ages.

Scanning proton microprobe analysis of otolith strontium (Sr) distribution was used to determine the life-history type (anadromous versus non-anadromous) of all dead-sampled Arctic Charr from 2003. These analyses were done using the proton microprobe located in the Department of Physics at the University of Guelph (Guelph, ON). The methodology is described in Babaluk et al. (2002). Laser ablation-inductively coupled-mass spectrometry (LA-ICP-MS) analysis of otolith Sr distribution was used to determine the life-history type of all dead-sampled Arctic Charr collected in 2005. These analyses were done using the laser instrument located in the Department of Geological Sciences at the University of Manitoba (Winnipeg, MB). The methodology is described in Babaluk et al. (2010). Both methods produce similar and comparable results (Campana et al. 1997) and permit a retrospective visualization of annual migrations to sea and subsequent returns to fresh water for over-wintering as annual peaks in otolith Sr levels.

In winter 2003, stomach contents of harvested Lake Trout and Arctic Charr were qualitatively described by visual observation in the field. During summer surveys, stomachs (Lake Trout, n=11; Arctic Charr, n=3) were removed from specimens in the field, preserved in ethanol, and later examined by North/South Consultants Inc. Stomachs were cut open lengthwise over a 500 micron sieve and washed thoroughly, making sure all contents and any parasites were removed. Total wet weight was recorded after removing as much water as possible from the material. Different items in the stomach were separated into weighing dishes, according to the following five groups: (1) all identifiable invertebrates, (2) all identifiable fish, (3) fish remains (parts of fish that are not immediately attributable to a given species such as scales, eggs, bones, tissue attached to bones), (4) otoliths, and (5) unidentifiable material (digested material that could not be attributed to anything specifically). Wet weights were obtained for each grouping. Whenever possible, invertebrates and fish were identified to lowest taxonomic level and enumerated.

DATA ANALYSES

Catch per unit effort (CPUE; no. of fish caught per net per unit of time) was used to measure the relative abundance of Arctic Charr and Lake Trout in Brock Lake. For the winter fishery, CPUE was estimated and standardized as the no. of fish caught per 100 m^2 gillnet per day, and reported separately for 114 mm and 140 mm mesh nets. For the July 2005 survey, CPUE was estimated as the no. of fish caught per 100 m^2 net per hour, and compared among the different mesh size panels of experimental nets (each standardized to an area of 100 m^2). In July 2004, missing data in regard to experimental net height precluded the estimation and standardization of net area for CPUE determination. As a result, CPUE values for July 2004 were estimated as the no. of fish caught per (55 m long) experimental net per hour. These data were compared among depth stratum and water temperature gradients. Harvest characteristics [total harvest weight (kg), mean weight of individual fish, and harvest-per-unit-effort (HUE)] were also compiled for the subsistence fishery of November 2003.

Somatic condition of Arctic Charr and Lake Trout was estimated using the condition factor K (Anderson and Gutreuter 1983). This was done to provide benchmark information on the condition of these species in Brock Lake. The K factor is a relative measure of body condition and "robustness" of a fish and was estimated as:

$$K = \frac{W \times 10^5}{L^3}$$

where: W = round weight in grams
L = fork length in millimetres.

Average fork length, weight and age information on Arctic Charr and Lake Trout was compiled but not compared statistically due to small sample sizes. Length frequency distributions for Arctic Charr and Lake Trout sampled in the winter fishery and summer surveys were plotted by 50 mm fork length intervals.

Non-parametric statistics were used to assess differences in CPUE between species and mesh sizes, and among depth stratum. All statistical analyses were conducted using SYSTAT 10 (Wilkinson 2003) software.

RESULTS

PHYSICAL AND CHEMICAL CHARACTERISTICS OF BROCK LAKE

Bathymetric maps of Brock Lake are presented in Figs 3 and 5. Table 1 summarizes lake area calculated by 5 m depth intervals and water volume calculated by 10 m depth intervals. Morphometric characteristics for the lake are summarized in Table 2. Based on our transect-depth data, mean lake depth was 10 m and maximum depth was 38 m. Most of the lake area (61% or ≈1.5 km^2) was under 10 m or less of water (Table 1, Fig. 3). Deeper areas (≥20 m) represented less than 10% of the lake surface and were discretely located in the main axis of the lake, but absent from the west basin and the east arm toward the lake outlet (Table 1, Figs 3 and 4). Total lake volume was equivalent to 0.012 km^3. The profundal zone (≥20 m depth) represented 9.5% (1.18×10^6 m^3) of the total lake volume (Table 1). The lake is relatively small (surface area = 2.5 km^2) with a large perimeter to area ratio (P:A = 6.6) indicating important littoral habitat availability. Variations in lake water levels were observed in July 2004, when water levels declined by ~25 cm during the course of the field survey (July 14-23). A high water mark was located at ~1 m above the lake water level observed on July 24, 2004, suggesting substantial seasonal water level fluctuations in Brock Lake.

Large and small cobbles was the dominant lake bottom substrate observed in 54 of the 84 transects where substrate was qualitatively examined (Fig. 5). Fine substrates were second in importance and were most predominant in the northern arm and south-eastern arm of the lake near the main inlet and outlet (Fig. 5). Submerged vegetation (macrophytes) was scarce and only observed near the lake's main inlet and outlet.

Brock Lake water quality parameters are summarized in Table 3. A depth-temperature profile indicated some thermal stratification of the water column in deeper areas of Brock

Lake (Fig. 6). A thermocline was observed between 5 m and 15 m depth at water quality stations 5 and 7 (Fig. 6). Benthic dissolved oxygen concentrations were not limiting to fish at the time of sampling (July 2004) (Table 3). Very low organic carbon (dissolved = 1.48 $mg \cdot L^{-1}$ and particulate = 0.25 $mg \cdot L^{-1}$) and nutrient concentrations (total phosphorus <0.01 $mg \cdot L^{-1}$, dissolved nitrogen = 0.07 $mg \cdot L^{-1}$ and NO_2+NO_3 <0.2 $mg \cdot L^{-1}$) indicated that the lake is highly oligotrophic and may only sustain limited algal productivity (Table 3).

The concentrations of 34 trace elements in water samples are presented in Appendix 1. Results confirm the relatively pristine status of Brock Lake. Strontium concentrations in the lake were low (mean = 9.4 $ug \cdot L^{-1}$), similar to other freshwater environments in the Canadian Arctic (Babaluk et al. 1997).

BIOLOGICAL SAMPLING

Zooplankton

In July 2004, the zooplankton community was dominated by copepods (Table 4, Fig. 7). The cyclopoid *Cyclops scutifer* and immature copepodites of various orders comprised 53% and 41% of the combined sample, respectively (Fig. 7). The calanoid copepods *Diaptomus* sp. and *Epischura* sp. and the cladocerans *Daphnia longiremis*, *Bosmina longirostris* and *Ceriodaphnia sp.* were also present in smaller numbers (Table 4).

Fish

Four different fish species were caught in Brock Lake and the associated inlets and outlets: Lake Trout, Arctic Charr, Slimy Sculpin (*Cottus cognatus*) and Arctic Grayling (*Thymallus arcticus*).

Adult Lake Trout and Arctic Charr were caught in the winter fishery in November 2003 (13 Arctic Charr, 7 Lake Trout) and during summer surveys in July 2004 (65 Lake Trout, 3 Arctic Charr) and 2005 (50 Lake Trout, 3 Arctic Charr). Lake Trout were caught throughout the lake in 33 of 61 test net sets in 2004, and 34 of 60 net sets in 2005 (Fig. 8). Arctic Charr were caught in gillnet set no. 16, 32 and 58 in 2004, and set no. 3, 36 and 46 in 2005 (Fig. 4). In 2004, juveniles of both species were captured in minnow

traps in a small inflowing stream located in the western basin of the lake (Fig. 8, Table 5). Small Lake Trout were also angled at the lake's main inlet in 2004 (Fig. 8, Table 5). One Arctic Charr parr (203 mm FL) was caught in gillnet set no. 32 (western basin) in 2004 (Fig. 4). Small (≤250 mm) Arctic Charr were caught during the subsistence fishery in Long Lake in November 2003 (Fig. 2).

Slimy Sculpin were caught in minnow traps and beach seine at Brock Lake's main inlet and at the mouth of the small inflowing stream in the western basin in 2004 (Fig. 8, Table 5). Arctic Grayling were angled in the Brock River downstream from the lake in 2004 (Fig. 8, Table 5).

FISH ABUNDANCE AND HARVEST CHARACTERISTICS

Winter fishery

Catch-per-unit-effort (CPUE) and harvest information on Lake Trout and Arctic Charr for the winter fishery of November 2003 are summarized in Table 6. All sets combined, Arctic Charr was the dominant species during winter, representing 65% of the catch and 67% of the total harvest by weight (Table 6). Arctic Charr and Lake Trout CPUE did not differ significantly between 114 mm and 140 mm mesh-size gillnets used for subsistence harvests [(Mann-Whitney) Lake Trout: $U = 20.5$, $p = 0.180$; Arctic Charr: $U = 19.0$, $p = 0.322$]. Arctic Charr abundance was relatively low with community fishers only catching 13 Arctic Charr in 11 sets over 3 days, which corresponded to a total harvest of 38 kg of Arctic Charr. Arctic Charr CPUE ranged from 1.1 (140 mm) to 1.9 (114 mm) Arctic Charr per 100 m^2 net per day (Table 6). Lake Trout abundance was slightly lower, ranging from 0.6 (140 mm) to 1.3 (114 mm) Lake Trout per net per day (Table 6). No significant difference in CPUE was observed between the two species in the winter fishery [(Mann-Whitney) 114 mm mesh gillnets: $U = 11.5$, $p = 0.309$; 140 mm mesh nets: $U = 29.0$, $p = 0.503$]. Harvest weight per unit effort (HUE) for Arctic Charr, however, was nearly double (at 4.1 kg per net per day) than that for Lake Trout (2.3 kg per net per day) (Table 6).

Summer surveys

CPUE information on Lake Trout and Arctic Charr for the summer surveys of 2004 and 2005 is presented in Tables 7 and 8, respectively. Lake Trout were dominant in Brock Lake during summer, accounting for 94-96% of the catch in test net sets. The remaining 4-6% consisted of Arctic Charr. Average Lake Trout CPUE were significantly higher than Arctic Charr CPUE in 2004 [(Mann Whitney) $U = 924.5$, $p < 0.0001$] and 2005 [(Mann Whitney) $U = 869.5$, $p < 0.0001$]. In 2004, Lake Trout abundance was equivalent to 1.1 Lake Trout per net hour, compared to 0.05 Arctic Charr per net hour (Table 7). In July 2005, Lake Trout abundance was 0.82 fish per 100 m^2 net per hour, compared to 0.06 for Arctic Charr (Table 8). CPUE values were not directly comparable between years due to the lack of net height information in 2004. In both years, most Lake Trout (>1.1) were caught in the larger (76 mm) mesh panel of experimental nets [(Kruskall-Wallis) 2004: $H = 6.207$, $p = 0.045$; 2005: $H = 13.443$, $p = 0.001$] (Tables 7 and 8). In 2004, there was a tendency for average Lake Trout CPUE to be higher (i.e., ≥1.3 Lake Trout per net hour) in shallower (<15 m) gillnet sets, but this difference was not statistically significant [(Kruskall-Wallis) $H = 3.964$, $p = 0.158$] (Table 9). Similarly, Arctic Charr CPUE was statistically similar among depth strata in 2004 [(Kruskall-Wallis) $H = 3.462$, $p = 0.177$], even given that no Arctic Charr were caught in gillnets set >15 m deep that year (Table 9). In contrast, in 2005, most (2/3) Arctic Charr were caught in locations (gillnet sets number 36 and 46) corresponding to depths >15 m (Fig. 4).

Angling, beach seining and minnow trapping catch and effort information for July 2004 are summarized in Table 5.

Tagged recaptures for Lake Trout (n=2) and Arctic Charr (n=0) over the course of the study were insufficient to constitute reliable information on fish movement/dispersal, or to estimate population size.

LIFE HISTORY

Figure 9 shows typical strontium distribution profiles from otoliths obtained from known non-anadromous (land-locked, resident) and known anadromous (sea-run) Arctic Charr. The pattern for the non-anadromous fish shows relatively constant, low strontium

throughout the otolith indicating that the fish occupied an environment of low strontium (i.e., fresh water) throughout its life (Fig. 9a). The pattern for the anadromous fish shows similarly low strontium for the first few years of its life (i.e., freshwater habitat) followed by pronounced oscillating increases in strontium (i.e., migrations to and from the sea) (Fig. 9b).

Based on the otolith strontium profiles for the Arctic Charr of known life histories (Fig. 9), all 13 Arctic Charr harvested from Brock Lake during the winter subsistence fishery of 2003 were anadromous (Fig. 10). The age at first migration to sea ranged from 2 to 4 years in females, and from 3 to 4 years in males (Fig. 10). Modal age at first migration was 3 years in both sexes. After their first migration, most Arctic Charr (11/13) migrated to and from the sea on an annual basis (Fig. 10). Only two females (sample AC_1 and AC_10) deviated from this pattern by spending two consecutive years in fresh water at age 7, possibly for spawning. Three specimens (AC_1, AC_4, and AC_10), through the course of their sea migrations, appeared to have migrated some years to estuarine areas (otolith Sr ~1000 ppm) and not full-strength sea-water (otolith Sr ~>1500 ppm). A maternal effect (presence of higher levels of strontium in the core area of otoliths (0-100 microns distance) was evident in eight of the 13 Arctic Charr samples analyzed (Fig. 10). This indicated that these fish were probably spawned by females that had migrated to and from the sea during the year that they spawned.

Otolith strontium profiles for the three Arctic Charr captured during the 2005 summer survey are shown in Fig. 11. One Arctic Charr was anadromous (sample AC_14) while the other two were non-anadromous (AC_15 and AC_16). The anadromous specimen first migrated to sea at the age of 3 and accomplished four annual migrations to sea before remaining in fresh water (Brock Lake) for three years until being captured in our study (sample AC_14 in Fig.11). This fish also appeared to have been spawned by a female that had migrated to sea the year that it spawned (as indicated by the presence of a maternal effect) (Fig. 11).

SIZE, AGE AND CONDITION

Biological characteristics on Arctic Charr from Brock Lake are summarized in Table 10. Anadromous Arctic Charr harvested during winter 2003 were larger than 550 mm (FL)

with a modal size of 650 mm (Fig. 12). Their mean fork length and age were equivalent to 656 mm and 8.4 years (Table 10). Anadromous males were larger (mean FL = 680 mm) and heavier (mean weight = 3.3 kg) than anadromous females (mean FL = 601 mm, mean weight = 2.1 kg), but mean age was similar between sexes (Table 10). Smaller Arctic Charr (<500 mm) were sampled during summer surveys (Fig. 12). The two non-anadromous (resident) Arctic Charr caught in summer 2005 had a mean fork length of 533 mm and a mean age of 11.5 years, suggesting smaller lengths-at-age of non-anadromous versus anadromous Arctic Charr in Brock Lake.

Available size (length and weight), age and body condition information for Lake Trout from Brock Lake is presented in Table 11. Larger Lake Trout were harvested in the winter fishery (mean FL = 612 mm, modal size = 550-650 mm, mean weight = 2.6 kg) relative to those caught during summer surveys (mean FL = 495-480 mm, modal size = 450 mm, mean weight = 1.5 kg) (Table 11, Fig. 13). This difference likely reflects that different gear was used. A broader range of Lake Trout sizes was observed in samples from summer surveys, with Lake Trout as large as 1000 mm being caught in 2004 (Fig. 13). Sexes pooled, Lake Trout specimens caught in July 2005 had a higher condition indices (mean K = 0.125) than Lake Trout caught in July 2004 (K = 0.115) and winter 2003 (K = 0.111) (Table 11). The average length, weight and age of male and female Lake Trout harvested during winter were comparable among individuals sampled. In July 2004, females were generally smaller (mean FL = 372 mm, mean weight = 0.6 kg) and younger (mean age = 8.5 yr) than males (mean FL = 457 mm, mean weight = 1.3 kg), mean age = 11.8 yr) (Table 11).

MATURITY AND SEX RATIOS

For both Arctic Charr and Lake Trout, males were more abundant than females in the samples. The sex ratio for anadromous Arctic Charr harvested in the winter fishery was approximately two males per female. Mature, current-year spawning Arctic Charr were caught at Brock Lake during both winter and summer. One anadromous post-spawner was harvested in the winter fishery, while current-year spawners were caught during summer surveys (n = 2 in 2004, and n = 1 in 2005).

The ratio of male to female Lake Trout in the winter fishery was 5:2 (2.5). Reliable maturity information for Lake Trout was only available for the summer survey of 2004, when a third (3/9) of all dead-sampled Lake Trout were sexually maturing males. All other specimens were either immature juveniles or resting adults.

STOMACH CONTENTS

All 13 anadromous Brock Lake Arctic Charr harvested in the winter fishery had empty stomachs. The stomachs of three Arctic Charr collected during the summer survey of 2005 contained benthic invertebrates (Table 12, Fig. 14). On average, invertebrates represented more than 73% of total wet weight stomach contents in Arctic Charr (the remainder weight consisting in other, unidentifiable materials) (Appendix 2). Trichoptera (*Grensia* sp.) and Diptera (mostly Chironomids) were the major prey items in Arctic Charr stomachs during summer (Fig. 14). The stomach of a non-anadromous (lake-resident) specimen (sample AC_3) mainly contained molluscs (the clam *Sphaerium nitidum* and the snail *Valvata sincera*) (Table 12). Based on field notes, a fish was found in the stomach of another non-anadromous Arctic Charr (sample AC_2) caught in 2005, but no biological information was collected. Surface water insects and Plecoptera larvae were absent from Arctic Charr stomachs.

In both summer surveys, stomach contents of Lake Trout from Brock Lake were dominated by larvae, pupae and adult stages of aquatic and terrestrial insects (Table 13, Fig. 15). Invertebrates represented more than 58% of total wet weight stomach contents in Lake Trout, the remaining weight mostly consisting in other, unidentifiable materials (Appendix 2). Eleven different invertebrate taxa were identified in Lake Trout stomachs (Table 13). In 2004, the diet of Lake Trout was largely dominated by chironomids (Fig. 15). In 2005, a broader diversity of insects were found in Lake Trout stomachs, though in smaller numbers (Table 13). Trichoptera (caddisflies), Diptera (mostly chironomids) and Plecoptera (stoneflies) were the most abundant taxa in 2005 (Fig. 15). Trichoptera found in Lake Trout stomachs included the genus *Grensia* sp. and the species *Apatania zonella* and *Hesperophylax incisus*. Plecoptera included the genera *Nemoura* sp., *Frisonia* sp. and *Frensia* sp. and the species *Arcynopteryx compacta*. Surface insects found in Lake Trout stomachs included coleopterans of the Dytiscidae (water beetle) and Carabidae (ground beetle) families, some Lepidoptera (moths and butterflies), water

boatman (Corixidae family), water mites (Hydracarina) and one unidentified Hymenoptera. Although no fish were found in Lake Trout stomachs examined in the laboratory, field observations suggested that piscivory was occurring with fish remains in the stomachs of three Lake Trout (n = 1 in winter 2003 and n = 2 in July 2005) and one Arctic Charr in the stomach of a Lake Trout specimen in July 2004.

PARASITES

The ectoparasite *Piscicola* sp. (leech) was observed on one Lake Trout and *Salmincola* sp. was observed on the gill rakers of another Lake Trout, both captured in 2004. The acanthocephalan *Echinorhynchus salmonis* was found in the gastrointestinal tracts of two Lake Trout (n = 1 in 2004 and n = 1 in 2005) and the same 2004 specimen also had *Cystidicola stigmatura* (nematodes) in its swim bladder. In total, external and internal parasites were observed in ~2% of Lake Trout sampled in Brock Lake, suggesting low parasite incidence in the population. Unidentified parasites were observed in the gonads of an anadromous male Arctic Charr caught in July 2005.

DISCUSSION

Fishery resources and habitat information on Brock Lake were examined using data collected during two consecutive summer surveys and a winter subsistence fishery. The lake has low productivity and relatively limited fish habitat potential, mainly due to its small size (2.5 km^2) and volume (0.02 km^3). Very low nutrient concentrations indicated limited autochthonous (algal) productivity in the lake. This was further supported by the paucity of strictly herbivorous zooplankton taxa commonly found in Arctic lakes (i.e., various orders of cladocerans and the calanoid copepod *Diaptomus pribilofensis* (Johnson et al. 2007). At the time of sampling, the zooplankton community was instead dominated by the copepod *Cyclops scutifer*, a species preferring cold and well-oxygenated hypolimnetic waters and characterized by an omnivorous diet consisting of algae, detritus, rotifers and copepod nauplii (Johnson et al. 2007). Most of the lake area (61%) was less than 10 m deep. Profundal areas (≥20 m) were discretely located in the main axis of the lake and represented less than 10% of the lake surface and 18% of total lake volume. This indicated small and patchy profundal niches for fish in the lake. A large

perimeter to area ratio, however, indicates extensive littoral habitat. Larger perimeter to area ratios have been shown to promote the aggregation of fish communities in the littoral zone of lakes (Scheuerell and Schindler 2004). However, our observation of a pronounced decrease in water levels during summer may limit overall littoral-benthic productivity in Brock Lake.

The Brock Lake fish community is composed of Arctic Charr, Lake Trout and Slimy Sculpin. Slimy Sculpin is a benthivorous fish and has been shown to feed primarily on chironomid larvae in an Alaskan lake located at a similar latitude to Brock Lake (Hershey and McDonald 1985). A fourth species, Arctic Grayling, was angled in the Brock River but not caught in the lake. These fish likely belong to a riverine population, as evidenced by their size range (360-435 mm FL) and absence from catches within the lake. Riverine populations of Arctic Grayling in Alaska have been shown to segregate spatially during summer, with larger and older fish occupying upstream areas near lake outlets (Hughes 1999). This supports our observation of large adult Arctic Grayling in the Brock River near Brock Lake in July. In contrast, lake-dwelling Arctic Grayling only briefly enter lake outlets for spawning at ice-out periods before returning to lakes and leaving outlet streams as nursery habitats for young-of-the-year (Jones et al. 2003).

Stomach content information for Arctic Charr and Lake Trout suggested that benthic productivity likely plays an important role in sustaining fish production in Brock Lake, at least on a seasonal basis. Chironomids were the most abundant benthic invertebrate taxon in fish stomachs during summertime, and typically dominate the benthos of high latitude Arctic lakes (Pinder 1995). Chironomids in more southern regions are typically found in profundal substrates yet they also occur in shallow littoral zones in Arctic environments where larger invertebrate forms are often absent (Hershey 1985). Trichoptera (caddisflies) and Plecoptera (stoneflies) larvae were the second most prevalent zoobenthos taxa in fish stomachs at the time of sampling. Caddisflies usually inhabit littoral zones, although the genus *Grensia* sp. (here found in the stomachs of both Lake Trout and Arctic Charr) has been shown to colonize the deeper benthos of Toolik Lake, Alaska (O'Brien et al. 1997). Stonefly larvae were only present in the stomachs of Lake Trout, along with surface water insects like coleopterans, hemipterans and hymenopterans. Stonefly larvae are characteristic of fast flowing streams or well aerated waters (i.e., wave-swept shores) of cold oligotrophic lakes (Ward 1992). The

clam *Sphaerium nitidum* was an important constituent of the diet of one resident (non-anadromous) Arctic Charr. The same specimen demonstrated the only occurrence of snails in fish stomachs from Brock Lake.

ARCTIC CHARR

Anadromous and non-anadromous Arctic Charr co-occur in Brock Lake. Anadromous Arctic Charr use freshwater environments such as Brock Lake for overwintering and possibly also for spawning. The Brock Lake system (including Brock Lake, Long Lake and other potential downstream/upstream locations) appear to be used for spawning and rearing, given the harvest of a post-spawning anadromous male in the winter fishery, small (≤250 mm) Arctic Charr in Long Lake during winter, and current-year spawners and juveniles during summer surveys. The western basin of Brock Lake, in particular, may be an important rearing area for Arctic Charr, as suggested by the presence of fry (at the mouth of a small inflowing stream) and a juvenile (parr) in one of the test nets in this portion of the lake.

Anadromous behaviour in fish is primarily related to differential productivity of freshwater and coastal ecosystems and the resulting costs-benefits balance of undertaking seaward migrations (Gross et al. 1988). The larger size-at-age of anadromous specimens harvested in Brock Lake during winter, relative to non-anadromous Arctic Charr caught in July 2005, supports the hypothesis that anadromy has a growth advantage. Unfortunately, our small sample size precludes quantitative comparisons of growth patterns between life-history types. The degree of anadromy (proportion of anadromous versus non-anadromous or resident fish) in Brock Lake Arctic Charr appeared high, since all specimens harvested in the winter fishery (i.e., at the time when both sea-run and resident fish should have been present in the lake) were anadromous. The degree of anadromy in lake-dwelling Arctic Charr populations has been shown to vary with physiological factors such as parr growth rate (Rikardsen and Elliott 2000) and physical characteristics of freshwater environments including lake depth and profundal zone volume (Kristoffersen et al. 1994), length of lake outlet rivers and a migration barrier index (combining migration distance and water velocity) (Kristoffersen 1994). The length of the Brock River (approx. 94 km) and the lake's elevation relative to sea level (390 m) imply high energy costs for upstream migrants. This is especially evident when

compared with the range of river lengths (0.3-7.0 km) and lake altitude (3-72 m) values considered by Kristoffersen (1994) to demonstrate the hypothesis of a negative relationship between energy expenditure during upstream migration and the degree of anadromy in Arctic Charr populations. In Brock Lake, it is possible that habitat and dietary constraints within the lake outweigh the negative effect of high energy costs during upstream migration to explain a high degree of anadromy in the Arctic Charr population. Hence, the lake has limited productivity and a small profundal volume (18%) which, according to Kristoffersen et al. (1994), should correspond to a high anadromy score. Limited profundal habitat and productivity forcing on the degree of anadromy in Brock Lake Arctic Charr may be further enhanced by the presence of Lake Trout. Hence, low-productivity arctic lakes such as Brock Lake are unlikely to support two large-bodied predators unless part of the fish community is sustained by the marine environment (Swanson et al. 2010).

The age-at-first-migration to sea in anadromous Arctic Charr from Brock Lake ranged from 2 to 4 years. Modal age-at-first-migration was 3 years in both sexes. Hornaday River Arctic Charr also had a modal age-at-first migration of 3+ years (Babaluk et al. 1998; J. Babaluk, unpublished data). This is younger than reported by Johnson (1989) for Arctic Charr from Nauyuk Lake (mean age-at-first-migration = 6 years), and younger than Arctic Charr from Spitsbergen, Svalbard Islands, Norway (mean age-at-first-migration = 6.7 years) (Radtke et al. 1996). Following the onset of anadromy, most Arctic Charr from Brock Lake demonstrated annual migratory patterns indicating obligate anadromy. Three specimens, however, deviated from this pattern and suggested the occurrence of facultative anadromy in Brock Lake Arctic Charr. These included two females captured in winter 2003 that remained in fresh water at age 7 (samples AC_1 and AC_10 in Fig. 10), and one male captured in July 2005 (sample AC_14 in Fig.11) showing consecutive annual migrations to sea between the ages of 3 to 6 before remaining in fresh water until capture at age 10. Facultative anadromy has been observed in other High Arctic systems (Craig 1989; Radtke et al. 1996; Babaluk et al. 2002). Facultative anadromy implies that Arctic Charr can migrate only when they are constrained to do so, and cease migrating either during the year that they spawn, in years when they lack sufficient energy reserves to do so, or when conditions of freshwater environments permit. We hypothesize that both females that did not migrate to sea at age 7 but resumed migrations at age 8 probably did so for spawning. In the

case of the male Arctic Charr sampled in 2005, we can speculate that the specimen ceased migrating once it had reached a size at which it became less vulnerable to predation by Lake Trout in the lake (predation on Arctic Charr by Lake Trout was evidenced by the finding of an Arctic Charr specimen in a Lake Trout stomach in July 2004). Alternatively, the male specimen was found to have heavily parasitized gonads. This infection may have contributed to reduce its overall fitness and capacity to undertake seaward migrations beyond age 6. The presence/absence of a maternal effect in otolith strontium distribution profiles suggested two types of spawning Arctic Charr in the anadromous component of the Brock Lake population: 1) those that migrate to sea during the year that they spawn, and 2) those that remain in fresh water during the year that they spawn. These observations further support the occurrence of facultative anadromy in Brock Lake Arctic Charr. A similar spawning strategy has been suggested for Arctic Charr from the nearby Hornaday River (Babaluk et al. 1998; J. Babaluk, unpublished data).

Arctic Charr abundance as CPUE was relatively low in the lake, indicating that the population is small. CPUE values were low in both the winter fishery and summer surveys. The characteristics of Brock Lake, mainly its small size, limited profundal habitat and low productivity likely limit the size of the Arctic Charr population. This may be further compounded by the presence of Lake Trout. Studies have shown that Arctic Charr is generally suppressed to the profundal zone of lakes by inter-specific interactions with Brown Trout (*Salmo trutta*) (Langeland et al. 1991; Kristoffersen et al. 1994; Saksgård and Hesthagen 2004) and the European Whitefish (*Coregonus lavaretus*) (Sandlund et al. 2010). Our limited dataset suggested that Arctic Charr and Lake Trout may similarly segregate between profundal and littoral habitats in Brock Lake during summer. Evidence for this included: 1) the high abundance of Lake Trout in the littoral test nets during summer surveys; 2) the complete absence of surface water insects and Plecoptera (stoneflies) larvae in the stomachs of Arctic Charr, which were omnipresent (though in small numbers) in the stomachs of Lake Trout; and 3) the capture of two (out of three) Arctic Charr in deeper (16-25 m deep) test nets in July 2005. Spatial segregation of Arctic Charr and Lake Trout may partly explain the weak occurrence of Arctic Charr in littoral test nets during summer surveys, together with the absence of anadromous specimens from the lake at the time of sampling. In contrast, the large extent of the littoral habitat in Brock Lake (as indicated mainly by a large perimeter to

area ratio), may facilitate transient or seasonal habitat overlap and prey partitioning between the two species. This would explain contradictory results with most (2/3) Arctic Charr caught in shallower (<5 m deep) test nets in summer 2004. Hence, the extent of habitat segregation between Arctic Charr and competing species has been shown to vary temporally (Langeland et al. 1991; Amundsen and Knudsen 2009) and with the occurrence and density of potential competitors (Knudsen et al. 2010, Sandlund et al. 2010). Based on our observations, we hypothesize that the size of the Arctic Charr population in Brock Lake is primarily limited by lake morphology as it determines the size of the profundal habitat and the potential for seasonal or transient habitat segregation with Lake Trout.

LAKE TROUT

Lake Trout was the dominant fish species observed during summer surveys in Brock Lake. Lake Trout abundance as CPUE was approximately one fish per net hour. This ranks relatively high compared to Yukon lakes surveyed using the same gear/technique. Lake Trout CPUE ranged between 0.33-0.60 fish per net hour in three lakes from southern Yukon with surface area (185-216 ha) and mean depth (7-15 m) similar to Brock Lake [N. Millar (Yukon Environment), unpublished data]. Likewise, CPUE in the range of 0.10-1.6 Lake Trout per net hour were observed in larger Yukon lakes (n = 17) with surface areas between 20-50 km^2 (Ferguson 2007). Comparatively high Lake Trout CPUE in Brock Lake may be linked to a different community composition (i.e., presence of Arctic Charr and absence of prey species like whitefish found in Yukon lakes), and to favourable conditions (like water temperatures <9°C and a high perimeter to area ratio) favouring the spatial aggregation of Lake Trout within the lake's littoral zone, where nets were set. In contrast, we observed a weak abundance of Lake Trout in samples from the winter subsistence fishery. Lake Trout CPUE in the upper pelagic zone of the lake during winter was approximately 25-fold lower than in littoral test nets during summer. This indicated that most of the Lake Trout population from Brock Lake may be closely associated with the littoral habitat. It also suggests that the absolute size of the Lake Trout population is probably intermediate (as opposed to large), as expected due to low lake productivity. Lower Lake Trout CPUE during winter could also be related to the presence of over-wintering anadromous Arctic Charr in the lake, which dominated the catch in subsistence gillnets. Spatial segregation between Arctic Charr and Lake Trout in

Brock Lake may explain the prevalence of Lake Trout in littoral test nets and that of Arctic Charr in gillnets set under the ice. Yet these observations remain confounded by seasonal and gear differences between our sampling events.

Lake Trout captured during summer surveys fed almost exclusively on benthic invertebrates and surface insects. This is consistent with the observation of benthos as the primary source of energy for Lake Trout in two arctic lakes in Alaska (Sierszen et al. 2003). It also supports the contention that Lake Trout are closely associated with a large littoral habitat in Brock Lake. Small, inter-annual differences in the diet composition of Lake Trout were likely related to the timing of abundance of different invertebrate taxa. Piscivory was observed but its incidence appeared to be limited and included predation on Arctic Charr. Stable isotope analyses of similar arctic fish communities suggested that only resident and pre-smolt Arctic Charr may fall prey to Lake Trout (Swanson et al. 2010). One Lake Trout specimen caught during the winter fishery had orange flesh suggesting a planktonic diet. However, like piscivory, the incidence of pelagic feeding by Lake Trout appeared to be limited. The sampling of fry (at the mouth of a small inflowing stream in the western basin) and juveniles (at the lake's main inlet) indicated rearing areas for Lake Trout in Brock Lake.

BROCK LAKE FOOD WEB

Feeding relationships within a system can be synthesized in a food web where individual populations/species are positioned into trophic levels (corresponding to successive levels of energy transfer), depending on who eats whom. A hypothetical representation of the Brock Lake food web is presented in Fig. 16. The examination of fish stomach contents suggested that fish production in Brock Lake is sustained primarily by benthic productivity, as observed for similar lake ecosystems in the Arctic (Sierszen et al. 2003). Occasional fish consumption by Arctic Charr and Lake Trout (including potential cannibalistic interactions often characterizing the ecology of these species at higher latitudes), would likely correspond to a four or five trophic levels food web. We positioned Arctic Charr and Lake Trout on the same trophic level (i.e., omnivorous fish). However, our data demonstrated that a large proportion of the Arctic Charr population in Brock Lake derives most of its energy from the marine environment. Anadromous Arctic Charr from similar arctic lakes were shown by Swanson et al. (2010) to occupy a higher trophic

position than resident Lake Trout, while resident and pre-smolt Arctic Charr occupied a lower trophic level than Lake Trout, as per stable isotope analyses. Parasites of Lake Trout were included in the Brock Lake food web. Depending on taxon, fish parasites can be at a higher, similar or lower trophic level than their host (Lafferty et al. 2008). Here, we positioned Lake Trout and their parasites on the same trophic level. Arctic Grayling was not positioned in the Brock Lake food web in light of evidence suggesting that the population is riverine and inhabits the Brock River. Riverine Arctic Grayling have been shown to feed opportunistically on lake-derived plankton and other invertebrates drifting from lake outlets (Jones et al. 2003).

SUMMARY

HABITAT

- Brock Lake is characterized mainly by its small size (2.5 km^2) and low productivity.

- The lake's morphology is distinguished by a large littoral habitat (perimeter to area ratio = 6.6) and by small and patchy profundal areas (≥20 m deep) together representing less than 10% of the lake's surface. These features may facilitate the co-occurrence of Arctic Charr and Lake Trout populations in Brock Lake.

- Large and small cobbles is the dominant bottom substrate type in Brock Lake.

- The western basin of the lake may be used as a rearing area for both Arctic Charr and Lake Trout, as indicated by the sampling of fry (from both species) and one Arctic Charr parr in this portion of the lake.

ARCTIC CHARR

- Both anadromous and resident life-history types of Arctic Charr coexist in Brock Lake.

- Brock Lake is an over-wintering area for sea-run Arctic Charr. The Brock Lake system (including Brock Lake, Long Lake and other potential downstream/upstream locations) also provides rearing areas for the species and is possibly used for spawning.

- The Arctic Charr population from Brock Lake is relatively small (based on CPUE information from both winter and summer) and characterized by a high degree of anadromy (based on the dominance of anadromous specimens (100%) in our winter sample). We hypothesized that these results were related to low lake productivity, limited profundal habitat availability, and the presence of Lake Trout.

- A tag return from 1999-2000 provided limited but significant evidence that Arctic Charr move between the Brock and Hornaday systems, and are thus not necessarily distinct populations. In this study, results of otolith microchemistry analyses demonstrate a similar age-at-first-migration and reproductive strategy (i.e., co-occurrence of specimens that migrate and do not migrate to sea during the year that they spawn) between Arctic Charr from Brock Lake and the Hornaday River, thereby further supporting the idea that these may belong to the same anadromous population.

LAKE TROUT

- CPUE values for Lake Trout in Brock Lake are low during winter.

- CPUE values for Lake Trout in Brock Lake in summer rank relatively high compared with similar-sized Yukon lakes.

- High Lake Trout density in littoral test nets and the dominance of zoobenthos and surface water insects in Lake Trout stomachs during summer, suggest that the Lake Trout population from Brock Lake is closely associated with the littoral habitat.

BROCK LAKE FOOD WEB

- The Brock Lake fish community consists of Arctic Charr, Lake Trout and Slimy Sculpin.

- Fish production in Brock Lake is primarily fuelled by benthic productivity, as observed in similar arctic lakes and demonstrated via the examination of fish stomach contents.

- A large proportion of the Brock Lake Arctic Charr population derives most of its energy from the marine environment.

- It is possible that Arctic Charr and Lake Trout spatially segregate between profundal and littoral habitats in Brock Lake. If it occurs, this spatial segregation may be variable over time.

- The occurrence of piscivory appears to be limited in both Arctic Charr and Lake Trout populations.

- Lake Trout prey upon on Arctic Charr in Brock Lake, as evidenced by the presence of an Arctic Charr specimen in a Lake Trout stomach in July 2004.

- Incidence of parasites in Lake Trout appears to be relatively low in Brock Lake

- A riverine Arctic Grayling population inhabits the Brock River and large adult Arctic Grayling were sampled in the river near the outlet of Brock Lake.

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Table 1. Bathymetric characteristics of Brock Lake. Surface area (m^2) by 5 m depth intervals and volume (m^3) by 10 m depth intervals.

Depth range	Area (10^5 m^2)	Area (%)	Volume (10^6 m^3)	Volume (%)
0-5 m	9.13	36.22		
5-10 m (0-10 m)	6.20	24.59	(7.62)	(61.25)
10-15 m	4.83	19.16		
15-20 m (10-20 m)	2.56	10.15	(3.64)	(29.26)
20-25 m	1.64	6.51		
25-30 m (20-30 m)	0.47	1.86	(1.00)	(8.04)
30-35 m	0.30	1.19		
35-40 m (30-40 m)	0.08	0.32	(0.18)	(1.45)
Brock Lake total	25.21	100.00	12.44	100.0

Table 2. Morphometric characteristics of Brock Lake.

Morphometric characteristic	Value
Lake area (ha)	252
Perimeter (km)	16.3
P:A ratio	6.6
Mean depth (m) (± 1 stdev)	10 ± 8
Max. depth (m)	38
Total volume (km^3)	0.02
Elevation (m)	390

Table 3. Summary of water quality parameters for Brock Lake. Mean values are presented by water layer and for the entire water column. Units are $mg \cdot L^{-1}$ unless otherwise specified.

		Water column strata			Water column
		Surface	Intermediate	Bottom	mean ± stdev
Physical-chemistry					
	Secchi (m)				7.5
	Temp (°C)	8.6	7.3	6.0	7.5 ± 1.5
	pH	7.4	7.3	7.1	7.3 ± 0.3
	DO	7.39	7.25	5.93	6.94 ± 0.80
	Salinity	0	0	0	0
	Conductivity	1.29	1.24	1.27	1.27 ± 0.10
	Alkalinity	65.7	64.0	64.0	64.5 ± 2.2
	Colour (TCU)	5	5	5	5
	TDS	59.0	62.0	66.0	62.3 ± 7.2
	TSS	<3	<3	<3	<3
	Turbidity (NTU)	0.79	0.68	0.57	0.68 ± 0.10
Nutrients and organics					
	Ammonia	<0.005	<0.005	<0.005	<0.005
	NO_2+NO_3	<0.2	<0.2	<0.2	<0.2
	N_Diss	0.130*	<0.04	<0.04	0.07 ± 0.10
	P_Diss	<0.01	<0.01	<0.01	<0.01
	P_Total	<0.01	<0.01	<0.01	<0.01
	DOC	1.5	1.5	1.4	1.5 ± 0.1
	POC	0.227	0.259	0.253	0.250 ± 0.020
	PON	0.046	0.039	0.034	0.040 ± 0.020
Other inorganics					
	SiO_2	1.22	1.24	1.27	1.24 ± 0.10
cations	Ca	15.1	14.6	14.7	14.8 ± 0.6
	Mg	8.44	8.15	8.19	8.30 ± 0.30
	Na	0.94	0.92	0.88	0.91 ± 0.04
	K	0.27	0.27	0.26	0.26 ± 0.02
anions	Cl	1.45	1.44	1.38	1.42 ± 0.10
	SO_4	4.94	4.79	4.79	4.84 ± 0.20
	F	0.01	0.01	0.01	0.01

Legend: Temp=temperature, DO=dissolved oxygen, TDS=total dissolved solids, TSS=total suspended solids, NO_2-NO_3=total nitrite + nitrate, N_Diss=dissolved nitrogen, P_Diss=dissolved phosphorous, P_total=total phosphorous, DOC=dissolved organic carbon, POC=particulate organic carbon, PON=particulate organic nitrogen, SiO_2=reactive silica, Ca=calcium, Mg=magnesium, Na=sodium, K=potassium, Cl=chlorine, SO_4=, F=fluorine.

*N_Diss concentration in surface water was 0.220 at one station and <0.04 at the other (average=0.130).

Approximate depth-range of different water layers: surface 0-5m, intermediate 5-10m, bottom >10m.

Table 4. Summary of abundance of zooplankton taxa collected from two sampling locations in Brock Lake in July 2004.

Location	Sample type	Identification	Frequency (no.)	Frequency (%)
Station 1	Vertical haul (12 m)	unident. imm. copepodites	402	42.58
		Cyclops scutifer	478	50.64
		Diaptomus pribilofensis	6	0.64
		Diaptomus sp. unid. males	2	0.21
		Diaptomus spp. females	42	4.45
		Epischura sp.	4	0.42
		Daphnia longiremis	9	0.95
		Bosmina longirostris	1	0.11
Station 2	Vertical haul (18 m)	unident. imm. copepodites	284	39.34
		Cyclops scutifer	395	54.71
		Diaptomus pribilofensis	8	1.11
		Diaptomus sp. unid. males	5	0.69
		Diaptomus spp. females	3	0.42
		Epischura sp.	13	1.80
		Daphnia longiremis	3	0.42
		Bosmina longirostris	10	1.39
		Ceriodaphnia sp.	1	0.14

Table 5. Summary of minnow trapping, beach seining and angling efforts and catches in Brock Lake, July 2004.

Gear	Location	Effort (hr)	Catch	Species and size of specimens caught
Minnow traps	main inlet	25.5	1	Slimy Sculpin (65 mm TL)
	main inlet	25.5	0	
	main inlet	25.5	0	
	outlet	23.5	0	
	outlet	23.5	0	
	west basin	15	2	Slimy Sculpin (108 mm, 112 mm (TL))
	west basin	15	4	Slimy Sculpin (63 mm (TL)), Lake Trout (39 mm, 102 mm, 120 mm (FL))
	west basin	15	3	Slimy Sculpin (39 mm (TL)), Arctic Charr (78 mm, 140 mm (FL))
	west basin	15	1	Lake Trout (133 mm (FL))
Beach seine	main inlet	260	1	Slimy Sculpin (30 mm (TL))
	main inlet	150	11	Slimy Sculpin (30 mm (TL) (on average))
	outlet	150	0	
	outlet	100	0	
Angling	main inlet	5	5	small Lake Trout
	main inlet (pools further upstream)	15	0	
	main inlet	180	6	Lake Trout
	outlet	45	5	Arctic Grayling (435 mm, 430 mm, 360 mm), Lake Trout (400 mm, 600 mm)

*angling effort = minutes·number of anglers.

Table 6. Catch information, average CPUE (mean ± 1 stdev) and harvest characteristics for the winter subsistence fishery conducted in Brock Lake, November 2003.

	114 mm mesh gillnets (4 sets)		140 mm mesh gillnets (7 sets)		Combined sample (11 sets)	
	Lake Trout	Arctic Charr	Lake Trout	Arctic Charr	Lake Trout	Arctic Charr
Catch (no. of fish)	5	9	2	4	7	13
% Catch by species	36	64	33	67	35	65
CPUE (no. of fish per 100 m^2 net per day)	1.27 ± 0.90	1.89 ± 1.50	0.64 ± 1.30	1.05 ± 1.60	0.87 ± 1.20	1.4 ± 1.50
Total harvest (kg)	13.10	26.20	5.30	11.48	18.40	37.70
% Harvest by species	33	67	32	68	33	67
Mean weight of harvested fish (kg)	2.62 ± 0.90	2.91 ± 0.80	2.65 ± 1.00	2.87 ± 0.70	2.62 ± 0.80	2.90 ± 0.70
HUE (kg per 100 m^2 net per day)	3.33	5.50	1.70	3.01	2.28	4.06

Table 7. Average CPUE (no. of fish per 55 m long net per hour ± 1 stdev) for Lake Trout and Arctic Charr caught in Brock Lake during the summer survey of July 2004.

Species	N	Full net	Mesh size		
	(No. of sets)	(Multi-mesh)	76 mm	38 mm	64 mm
Lake Trout	61	1.05 ± 1.30	1.56 ± 2.80	0.53 ± 1.50	1.06 ± 2.20
Arctic Charr	61	0.05 ± 0.20	0.10 ± 0.50	0.05 ± 0.40	0

Table 8. Average CPUE (no. of fish per 100 m^2 net per hour ± 1 stdev) for Lake Trout and Arctic Charr caught in Brock Lake during the summer survey of July 2005.

Species	N	Full net	Mesh size		
	(No. of sets)	(Multi-mesh)	76 mm	38 mm	64 mm
Lake Trout	60	0.82 ± 1.10	1.49 ± 2.50	0.48 ± 1.50	0.50 ± 1.70
Arctic Charr	60	0.06 ± 0.30	0.06 ± 0.50	0	0.11 ± 0.60

Table 9. Average CPUE (no. of fish per 55 m long net per hour ± 1 stdev) by net depth stratum for Lake Trout and Arctic Charr caught in Brock Lake during the summer survey of July 2004.

Net depth (m)	No. of sets	Lake Trout CPUE	Arctic Charr CPUE
≤5	15	1.33 ± 1.5	0.13 ± 0.4
5-15	22	1.42 ± 1.6	0.05 ± 0.2
16-25	24	0.54 ± 0.7	0

Table 10. Biological characteristics (fork length, age, weight, and body condition) for Arctic Charr collected in Brock Lake during the winter fishery (2003) and summer surveys (2004 and 2005).

	Fork length (mm)			Age (yr)			Weight (g)			Condition (K)	
	N	Mean ± stdev	Range	N	Mean ± stdev	Range	N	Mean ± stdev	Range	N	Mean ± stdev
Sexes pooled											
2003	13	656 ± 46	575 - 728	13	8.4 ± 0.5	8 - 9	13	2898 ± 706	1850 - 4400	13	0.101 ± 0.007
2004	3	496 ± 254	203 - 647	0			3	1842 ± 1530	75 - 2750	3	0.098 ± 0.008
2005	3	578 ± 90	490 - 670	3	11.0 ± 2.6	9 - 14	3	2000 ± 563	1350 - 2350	3	0.105 ± 0.025
Male											
2003	9	680 ± 27	645 - 728	9	8.3 ± 0.5	8 - 9	9	3253 ± 512	2650 - 4400	9	0.103 ± 0.007
2005	2	580 ± 127	490 - 670	2	12.0 ± 2.8	10 - 14	2	1825 ± 672	1350 - 2300	2	0.096 ± 0.027
Female											
2003	4	601 ± 24	575 - 630	4	8.5 ± 0.6	8 - 9	4	2100 ± 252	1850 - 2450	4	0.096 ± 0.004
2005	1	575		1	9.0		1	2350		1	0.124

Table 11. Biological characteristics (fork length, age, weight, and body condition) for Lake Trout collected in Brock Lake during the winter fishery (2003) and summer surveys (2004 and 2005).

		Fork length (mm)			Age (yr)			Weight (g)		Condition (K)	
	N	Mean ± stdev	Range	N	Mean ± stdev	Range	N	Mean ± stdev	Range	N	Mean ± stdev
Sexes pooled											
2003	7	612 ± 65	530 - 690	0			7	2629 ± 819	1600 - 3600	7	0.111 ± 0.006
2004	65	495 ± 128	298 - 1000	8	11.0 ± 2.5	6 - 15	64	1479 ± 1251	300 - 8450	64	0.115 ± 0.023
2005	53	480 ± 96	210 - 732	2	13.0 ± 2.8	11 - 15	53	1510 ± 911	150 - 4400	53	0.125 ± 0.020
Male											
2003	5	617 ± 60	565 - 690	0			5	2680 ± 769	1900 - 3600	5	0.112 ± 0.007
2004	7	457 ± 55	382 - 556	6	11.8 ± 1.7	10 - 15	7	1283 ± 588	650 - 2300	7	0.134 ± 0.055
2005	0			0			0			0	
Female											
2003	2	601 ± 100	530 - 672	0			2	2500 ± 1273	1600 - 3400	2	0.110 ± 0.003
2004	2	372 ± 90	308 - 435	2	8.5 ± 3.5	6 - 11	2	600 ± 424	300 - 900	2	0.106 ± 0.005
2005	3	543 ± 66	472 - 604	2	13.0 ± 2.8	11 - 15	3	1967 ± 679	1250 - 2600	3	0.120 ± 0.002

Table 12. Invertebrate stomach contents for three Arctic Charr specimens collected in Brock Lake in July 2005. Invertebrates are presented by order or class, distinguished by life-stage and further identified to family or species, when possible.

			Stomach contents			
Sample	Fork length (mm)	Life-history	Order or Class	Life-stage	N	Details
AC_1	670	anadromous	Diptera	larvae, pupae	379	Chironomidae (n=376) and Tipulidae (n=3)
AC_2	575	resident	Trichoptera	cases, larvae	527	*Grensia* sp.
AC_3	490	resident	Bivalvia	adult	263	species:*Sphaerium nitidum*
			Diptera	pupae	3	family:Chironomidae
			Gastropoda	adult	9	species:*Valvata sincera*

Table 13. Invertebrate stomach contents for Lake Trout specimens collected in Brock Lake during summer surveys (July 2004 and 2005). Invertebrates are presented by order and distinguished by life-stage. Different orders were further identified to family or species, when possible.

			Stomach contents			
Year	Sample	Fork length (mm)	Order	Life-stage	N	Details
2004	LT_1	450	Coleoptera	adult	11	Dytiscidae (n=6), Carabidae (n=5)
			Diptera	adult, larvae, pupae	522	Chironomidae (n=520),Tipulidae (n=2)
			Lepidoptera	adult	3	
			Plecoptera	adult, nymph	13	*Nemoura* sp. (n=8), *Arcynopteryx compacta* (n=4), *Frisonia* sp.(n=1)
			Trichoptera	adult, pupae	14	*Apatania zonella* (n=13), *Hesperophylax incisus* (n=1)
2004	LT_2	382	Copepoda	adult	3	
			Diptera	pupae	3508	Chironomidae (n=3504), Tipulidae (n=4)
			Trichoptera	pupae	9	species: *Apatania zonella*
2004	LT_3	556	Trichoptera	cases, pupae, larvae	194	*Grensia* sp. (n=193)
2004	LT_4	420	Diptera	adult, larvae, pupae	4778	Chironomidae (n=4737), Tipulidae
			Hemiptera	adult	1	Corixidae
			Hymenoptera	adult	1	
			Lepidoptera	adult	2	
			Plecoptera	adult, nymph	12	*Arcynopteryx compacta* (n=7), *Nemoura* sp. (n=5)
			Trichoptera	pupae	30	*Apatania zonella* (n=22), *Hesperophylax incisus* (n=8)
2004	LT_5	308	Diptera	larvae, pupae	155	Chironomidae
			Trichoptera	pupae	1	*Hesperophylax incisus*
2004	LT_6	480	Diptera	larvae, pupae	2767	Chironomidae
			Lepidoptera	adult	4	
			Plecoptera	adult, nymph	8	*Arcynopteryx compacta* (n=4), *Nemoura* sp. (n=3), *Frensia* sp. (n=1)
			Trichoptera	adult, pupae	58	*Hesperophylax incisus* (n=20), *Grensia* sp. (n=2)
2004	LT_7	438	Diptera	larvae, pupae	531	Chironomidae
			Parasites	adult	6	
			Trichoptera	adult, pupae	17	*Hesperophylax incisus* (n=16)
2004	LT_8	435	Coleoptera	adult	6	
			Diptera	adult, larvae, pupae	3152	Chironomidae (n=3140), Tipulidae
			Nematoda	adult	2	
			Hydracarina	adult	1	
			Plecoptera	adult, nymph	8	*Nemoura* sp. (n=4), *Arcynopteryx compacta* (n=3), *Frensia* sp.(n=1)
			Trichoptera	adult, pupae	17	*Apatania zonella* (n=14), *Hesperophylax incisus* (n=3)
			Lepidoptera	adult	1	
2004	LT_9	474	Bivalvia	adult	4	Sphaeriidae
			Coleoptera	adult	2	(body parts)
			Diptera	larvae, pupae	2407	Chironomidae
			Hydracarina	adult	1	
			Nematoda	adult	1	
			Plecoptera	adult	1	*Arcynopteryx compacta*
2005	LT_10	472	Diptera	pupae	4	Chironomidae
			Coleoptera	adult	1	(body parts)
			Nematoda (phylum)	adult	2	
			Plecoptera	adult	3	*Arcynopteryx compacta*
			Trichoptera	cases only	7	*Grensia* sp.
2005	LT_11	604	Coleoptera	adult	1	(body parts)
			Diptera	larvae, pupae	4	Chironomidae
			Plecoptera	adult	3	
			Trichoptera	cases, pupae	3	*Apatania zonella*

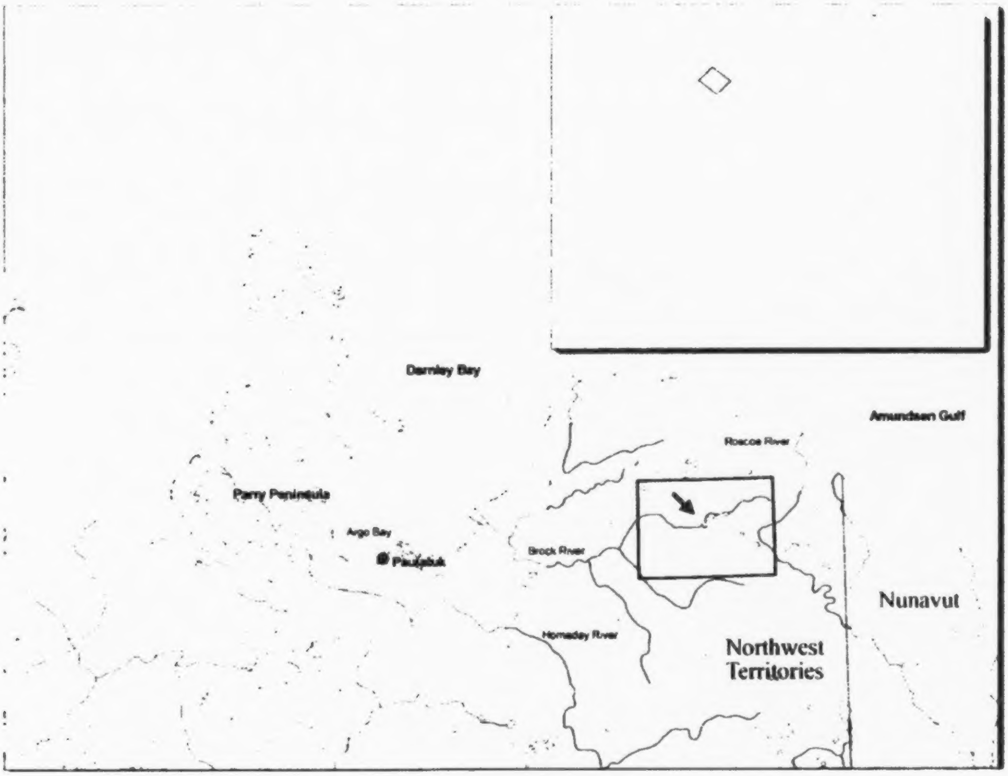

Figure 1. Map of the Paulatuk area, Northwest Territories, showing the Hornaday River and the northern portion of Tuktut Nogait National Park (shaded area) with the emplacement of Brock Lake (black rectangle and arrow).

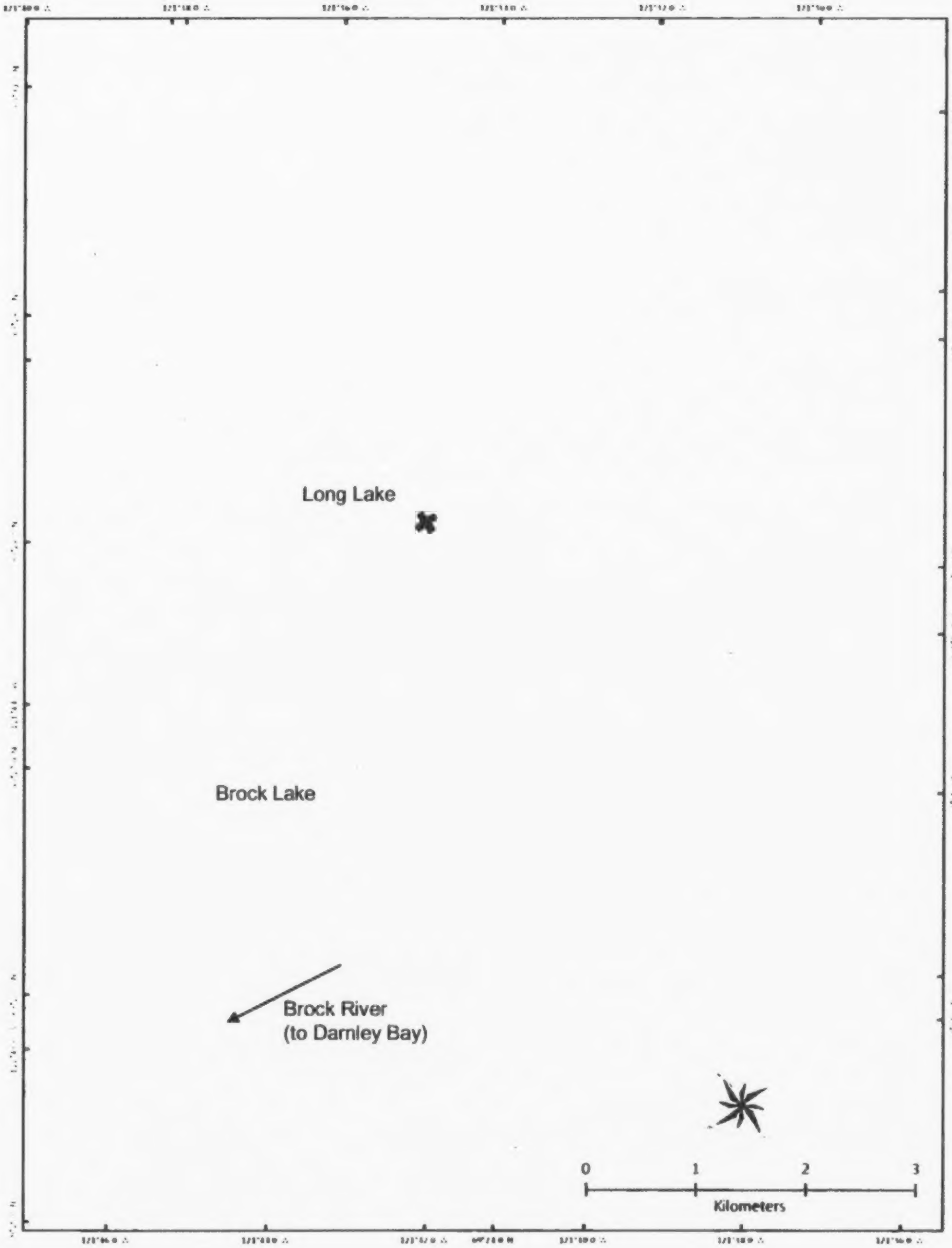

Figure 2. Map of the Brock Lake system showing Long Lake and the emplacement of subsistence harvests of small (<250 mm) Arctic Charr in Long Lake in November 2003 (red cross).

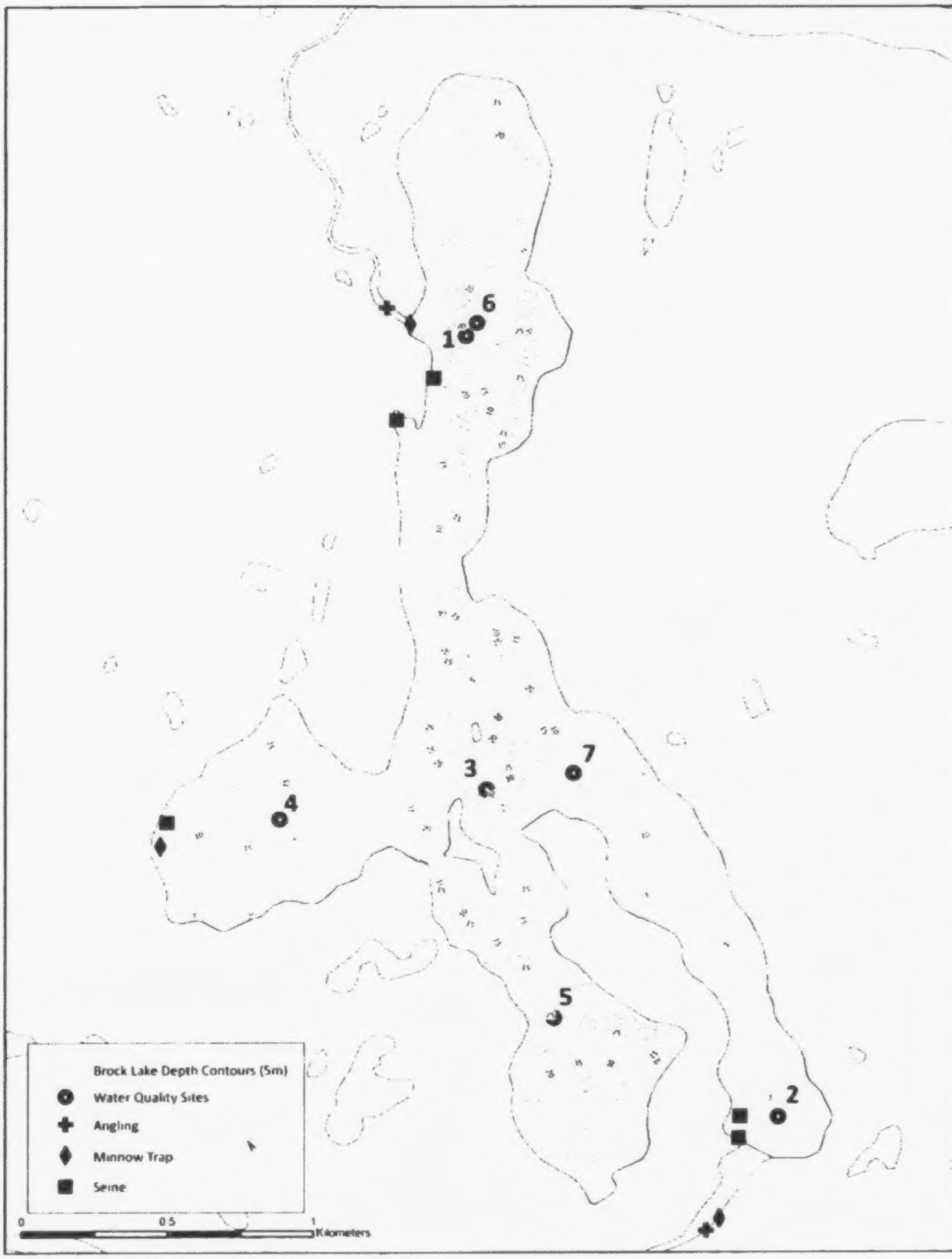

Figure 3. Bathymetric map of Brock Lake showing the emplacement of water quality sampling (sites 1 to 7) and angling, minnow trapping, and seining locations, July 2004.

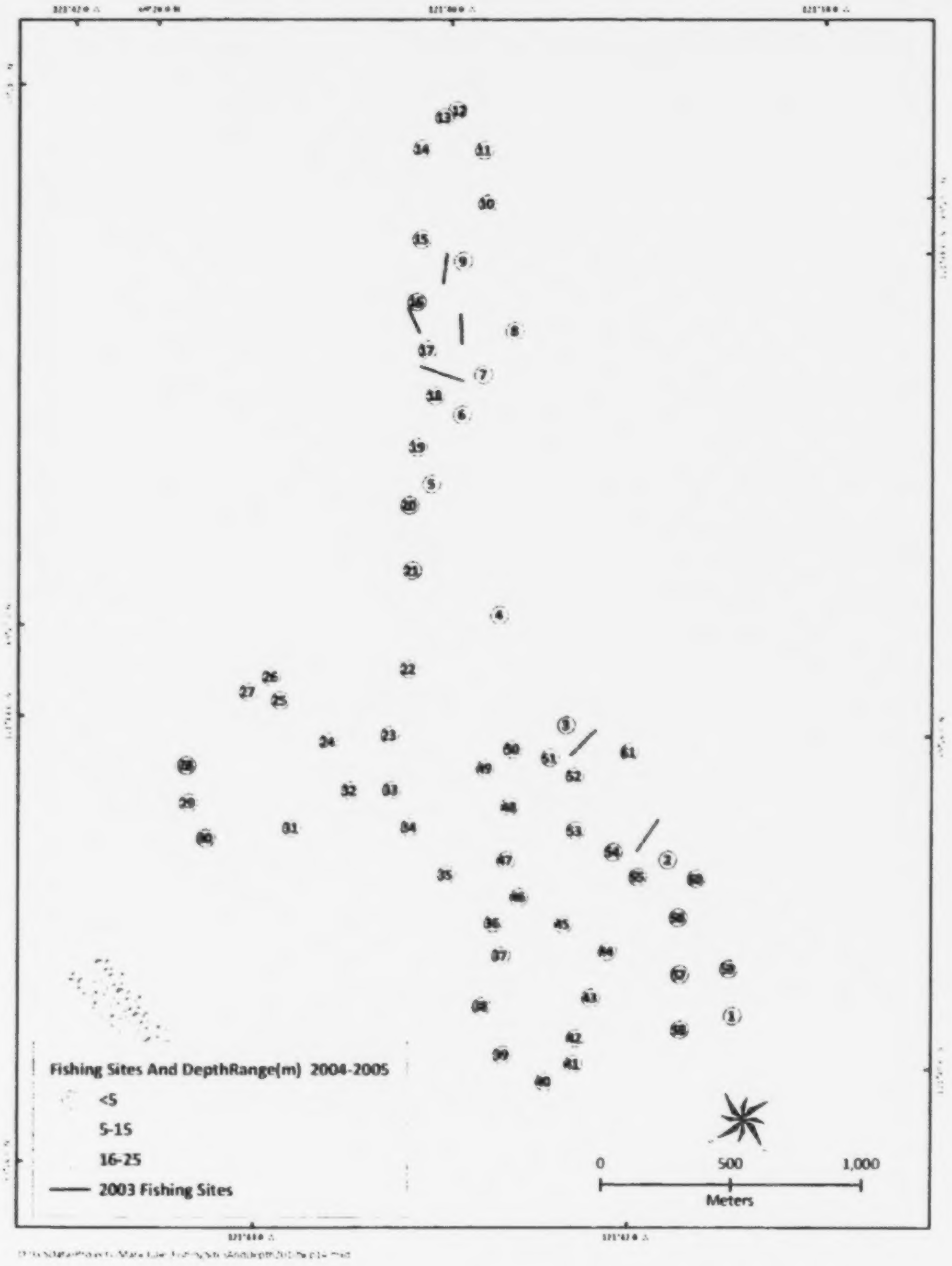

Figure 4. Map of Brock Lake showing subsistence fishing sites in winter 2003 and test netting sites for the summer surveys of July 2004 and 2005. Net depth was measured in 2004. Test netting site no. 61 was only used in July 2004.

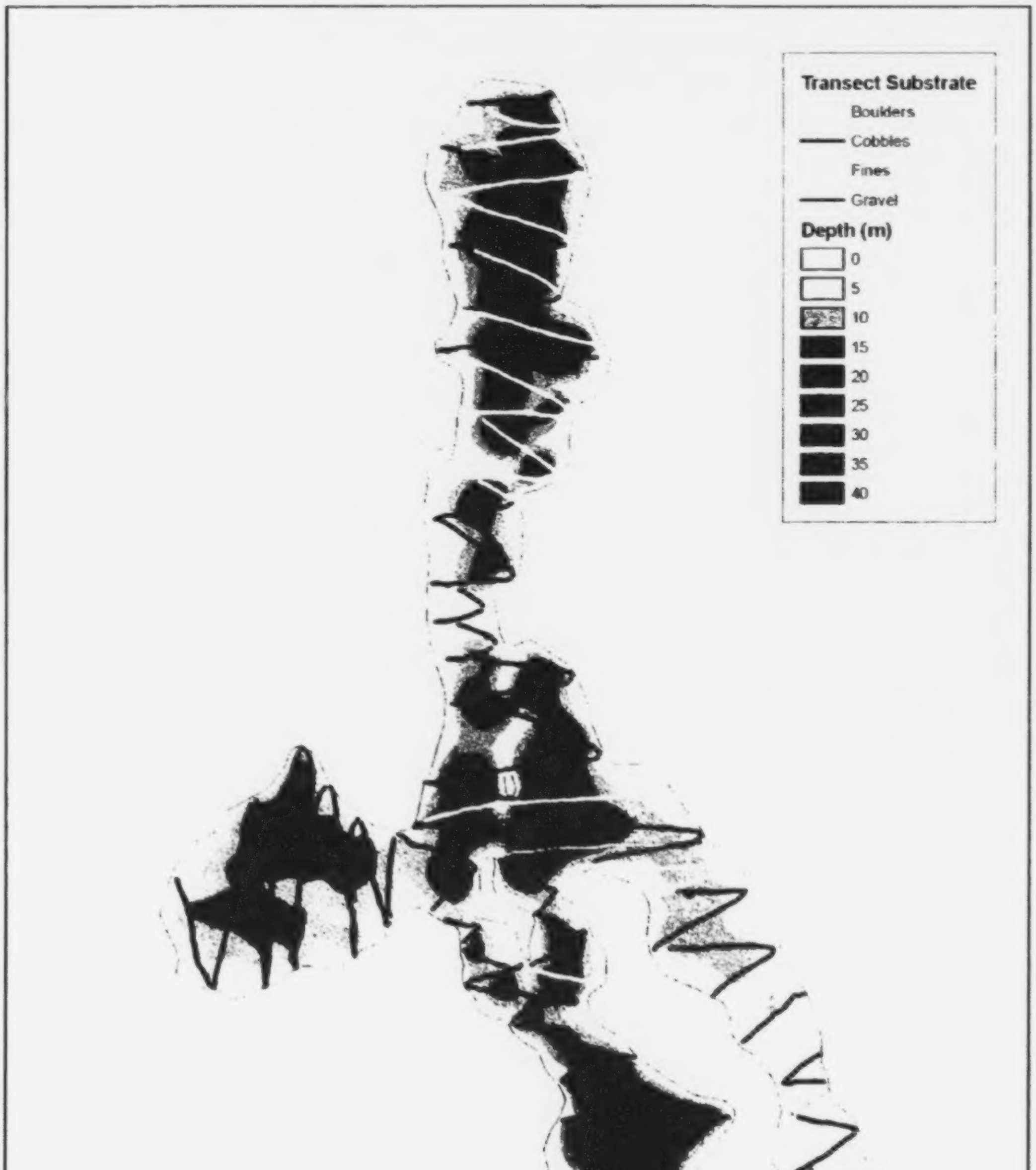

Figure 5. Bathymetric map of Brock Lake showing dominant bottom substrate qualitatively identified over 84 depth-sounding transects.

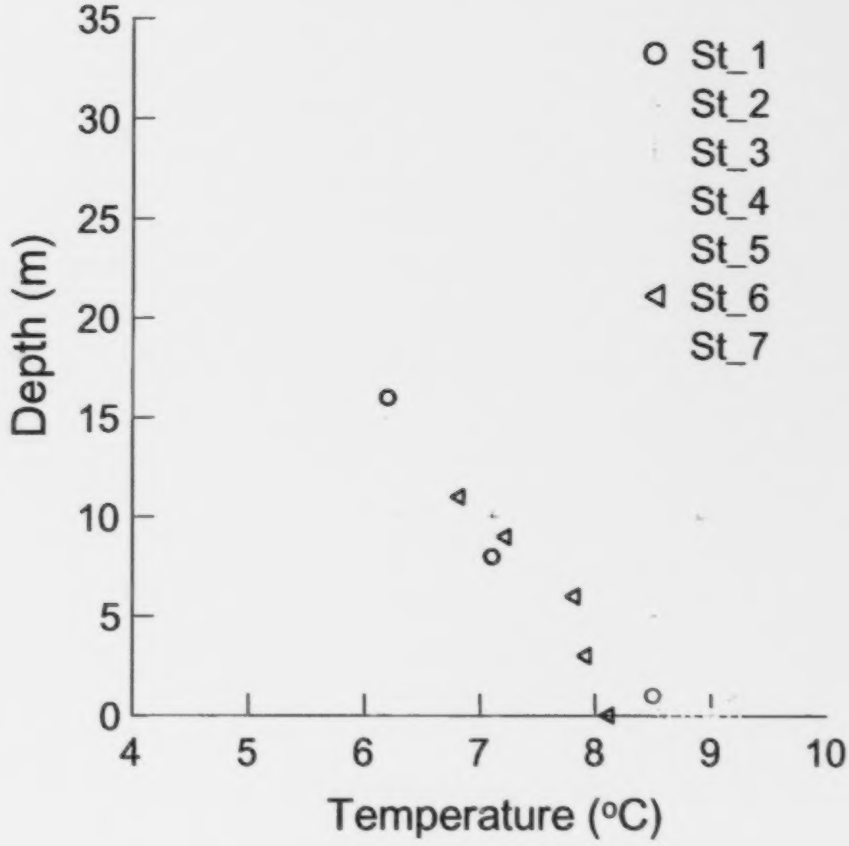

Figure 6. Water temperature profile with depth for Brock Lake water quality stations number 1 to 7.

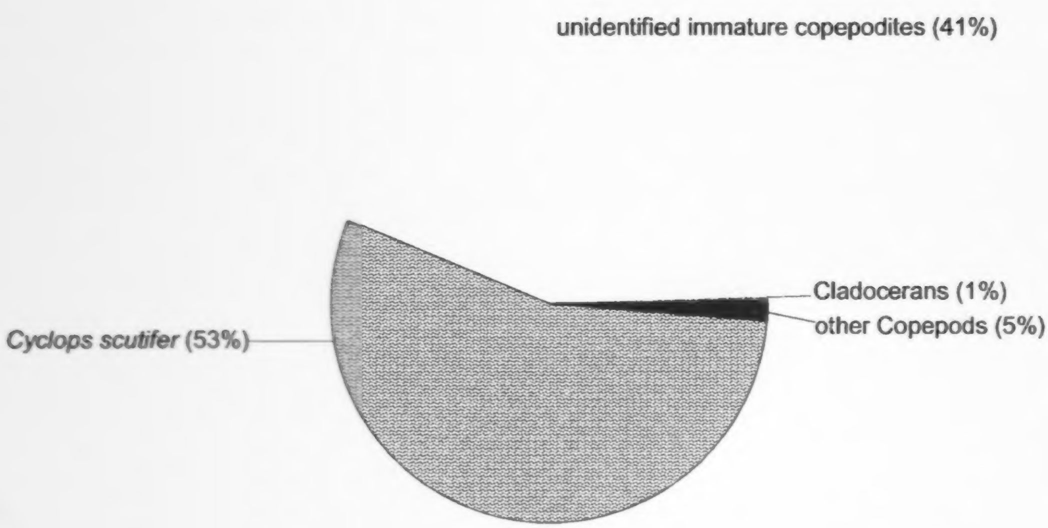

Figure 7. Proportions of zooplankton taxa in the combined sample (data pooled from two sampling locations) from Brock Lake, July 2004.

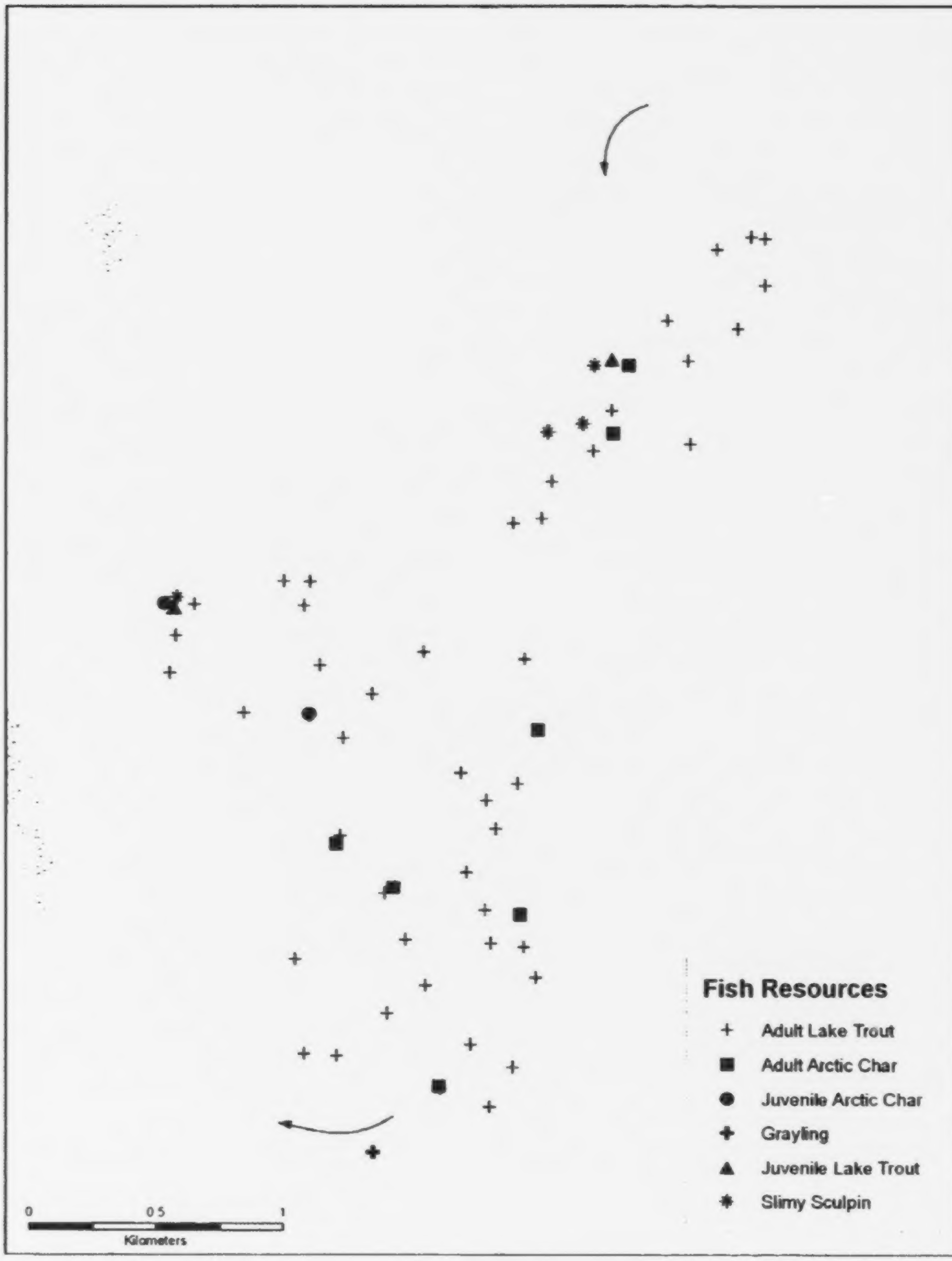

Figure 8. Summary of fish resources in Brock Lake, by species and location, based on information gathered during winter harvests (2003) and summer surveys (2004-2005).

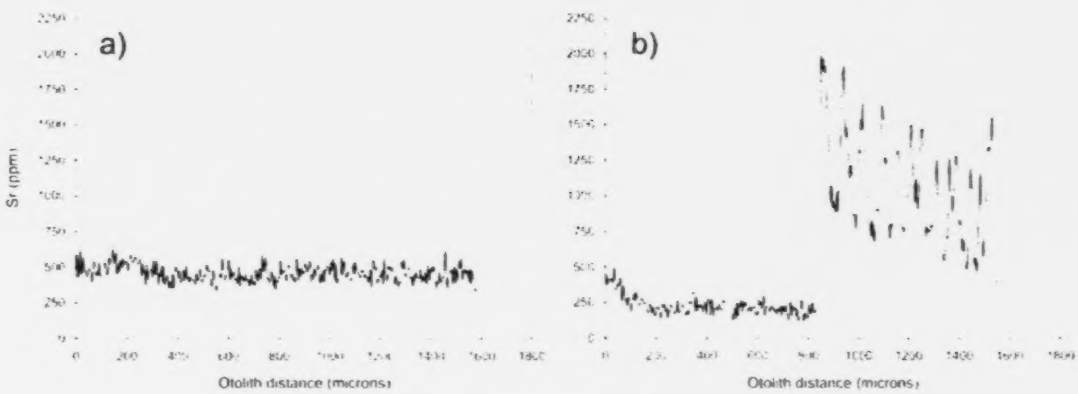

Figure 9. Typical Sr profiles of otoliths from (a) non-anadromous and (b) anadromous Arctic Charr (modified from Babaluk et al. 1997).

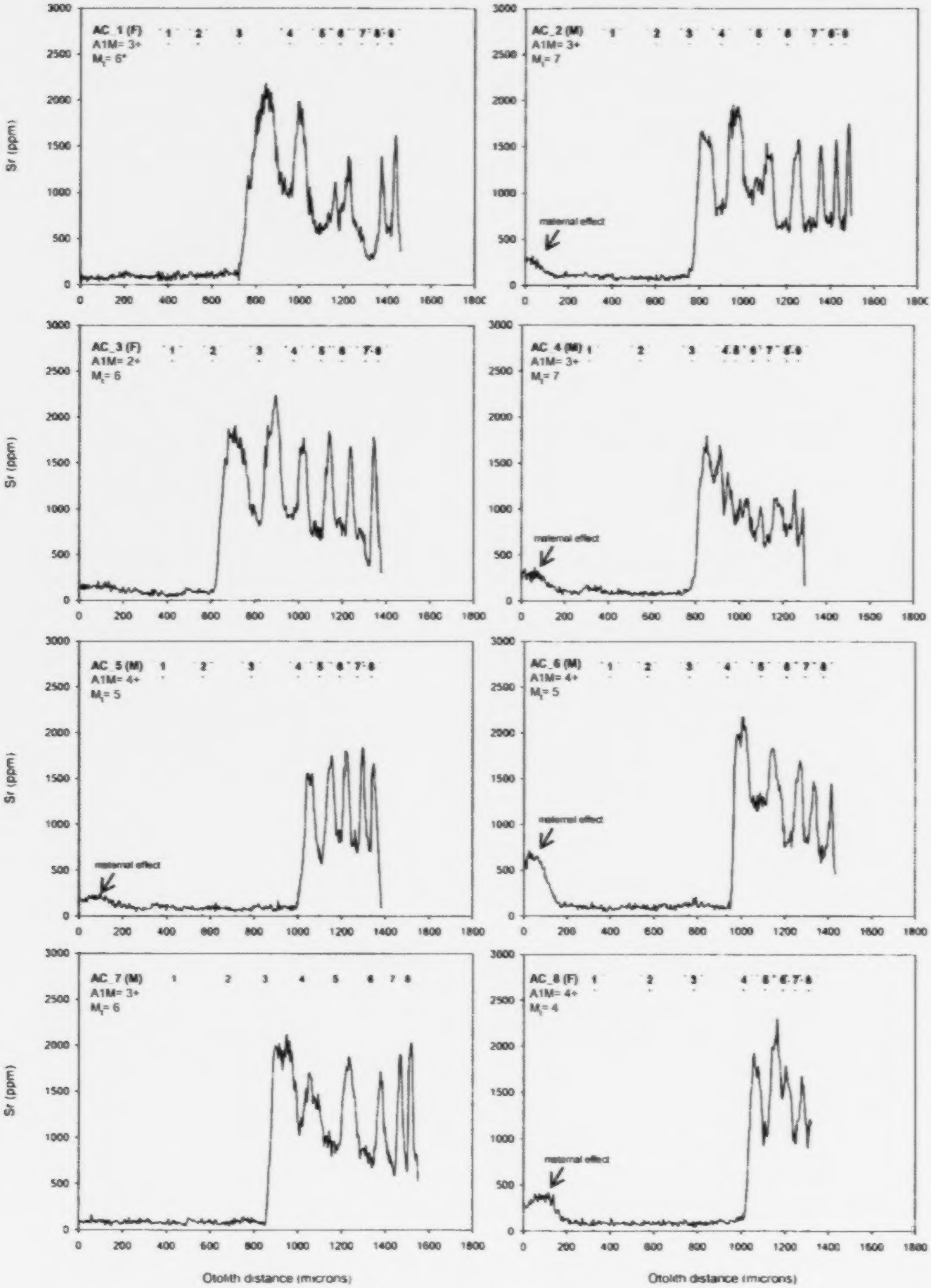

Figure 10. Strontium profiles of otoliths from Arctic Charr collected in Brock Lake in November 2003. Numbered triangles and dashed lines indicate approximate location of annuli (age in years). M=male, F=female. A1M=age-at-first-migration to sea. M_t=total number of migrations during lifespan (*indicate that not all migrations were annual). Maternal effect is indicated where present.

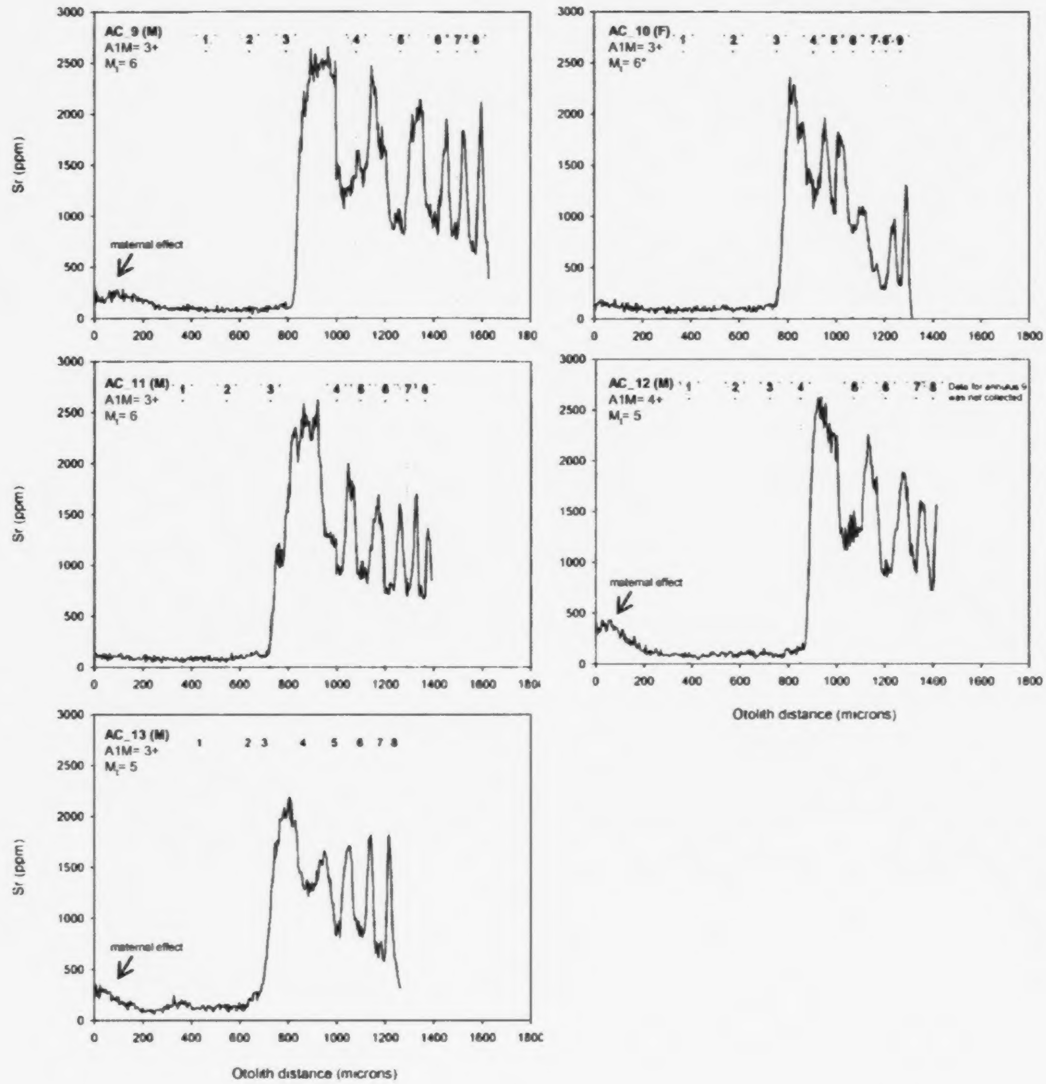

Figure 10. Continued.

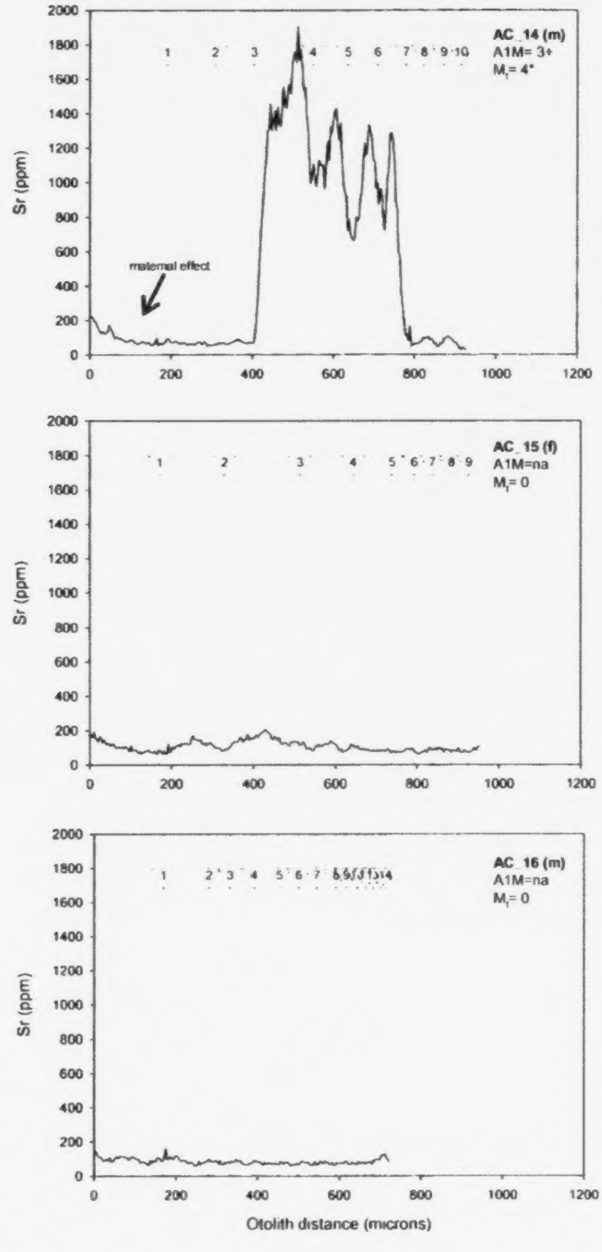

Figure 11. Strontium profiles of otoliths from Arctic Charr collected in Brock Lake in July 2005. Numbered triangles and dashed lines indicate approx. location of annuli (age in years). (m)=male, (f)=female. A1M=age-at-first-migration to sea. M_t=total number of migrations during lifespan (*indicate that not all migrations were annual). Maternal effect is indicated where present.

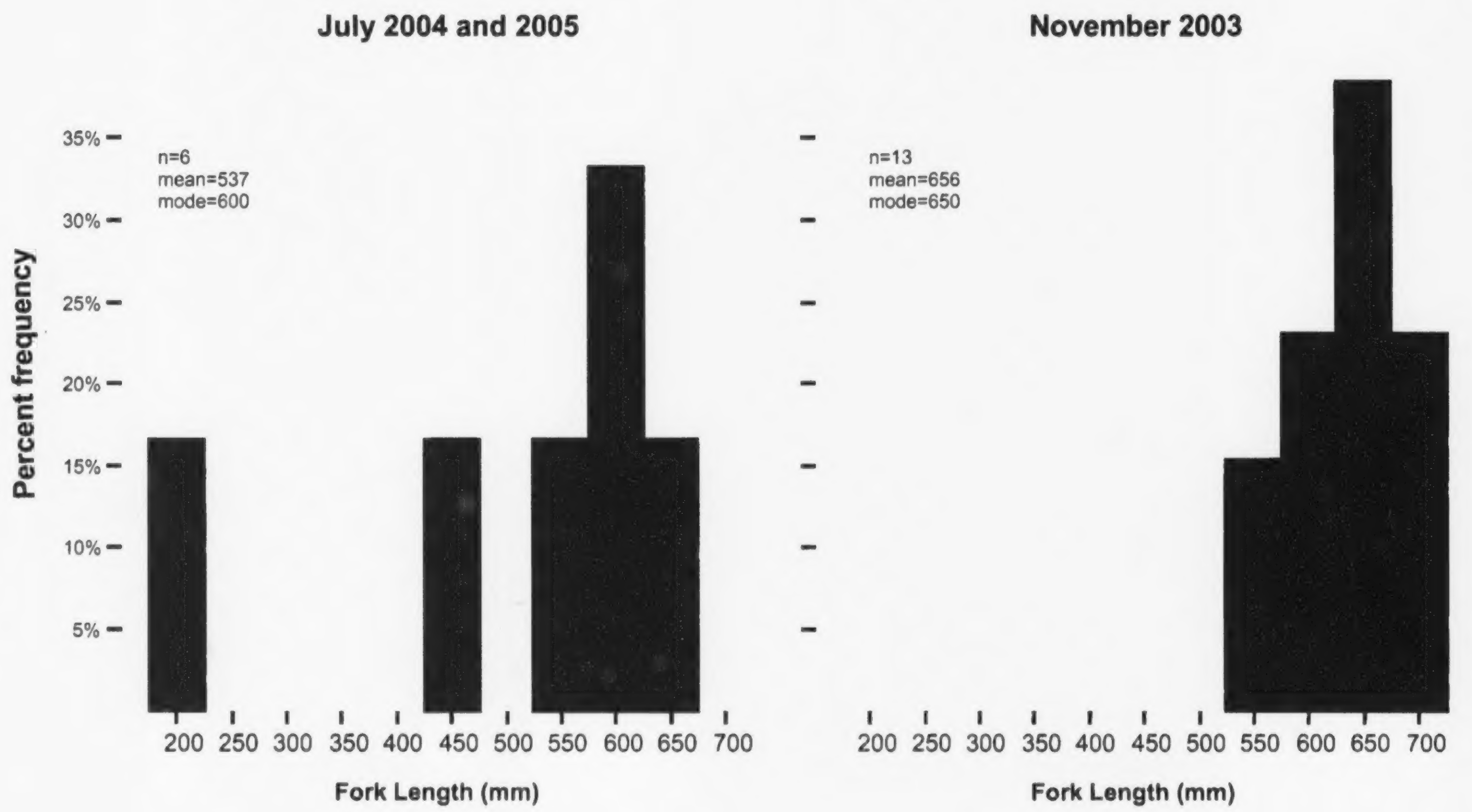

Figure 12. Percent length frequency distributions (50 mm FL intervals) for Arctic Charr caught in Brock Lake during summer surveys (July 2004 and 2005) and harvested in the winter fishery (November 2003).

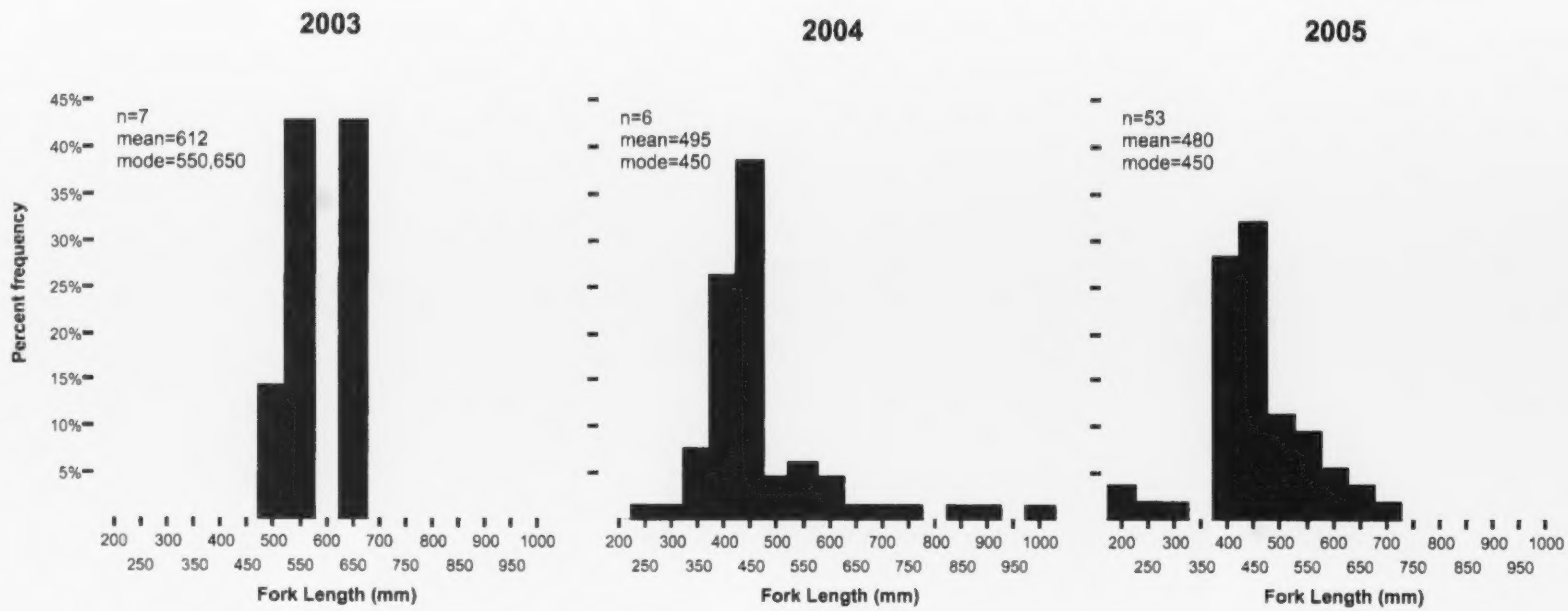

Figure 13. Percent length frequency distributions (50mm FL intervals) for Lake Trout caught in Brock Lake during the winter fishery of November 2003 and summer surveys (experimental netting) in July 2004 and 2005.

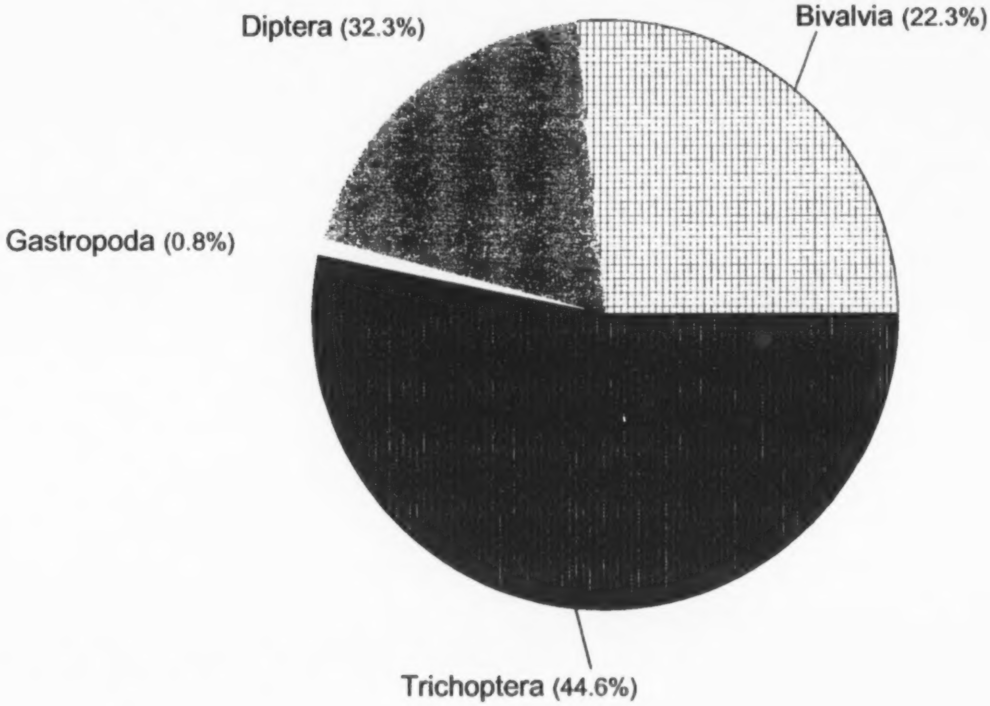

Figure 14. Summary of invertebrate stomach content for Arctic Charr specimens collected in Brock Lake during the summer survey of July 2005.

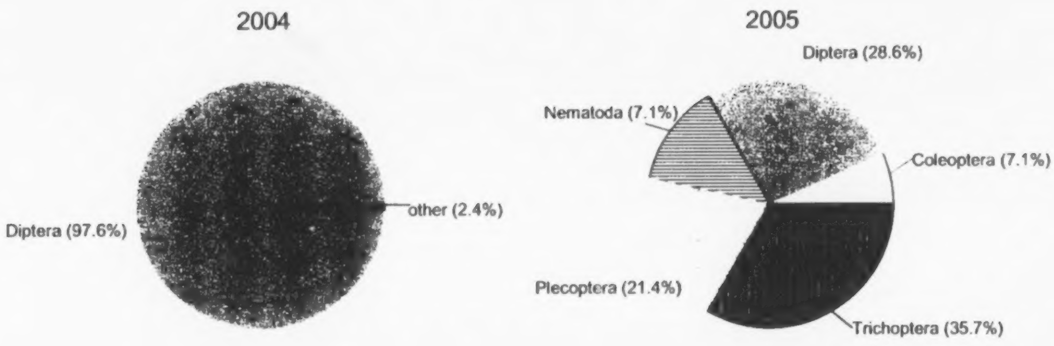

Figure 15. Summary of invertebrate stomach content for Lake Trout specimens collected in Brock Lake during summer surveys of July 2004 and 2005.

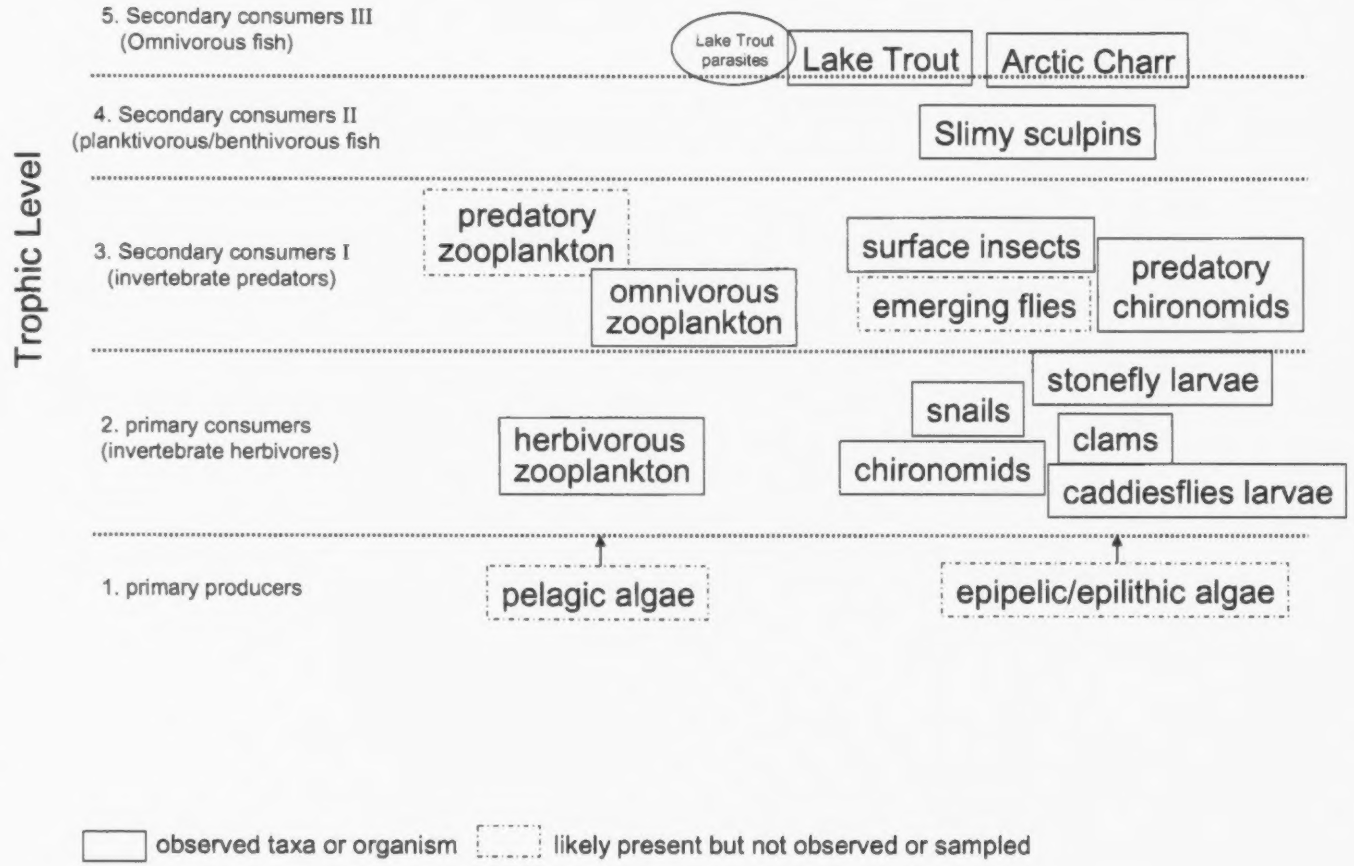

Figure 16. Theoretical Brock Lake food web, based on data collected in this study. Arctic Charr includes both resident and anadromous life-history types.

Appendix 1. Concentrations (in $\mu g \cdot L^{-1}$) of 34 trace elements in Brock Lake water samples. Values in ( ) indicate half detection limit.

Element	Water column strata			Water column
	Surface	Intermediate	Bottom	mean ± stdev
Ag (silver)	0.006 ± 0.002	0.04 ± 0.04	0.01 ± 0.001	0.02 ± 0.02
Al (aluminum)	(0.1)	(0.1)	0.65 ± 0.5	0.3 ± 0.4
As (arsenic)	0.02	0.02 ± 0.01	0.02 ± 0.01	0.02 ± 0.01
B (boron)	(0.1)	(0.1)	(0.1)	(0.1)
Ba (barium)	10.1	9.9 ± 0.3	9.7 ± 0.5	9.9 ± 0.3
Be (beryllium)	(0.001)	(0.001)	(0.001)	(0.001)
Bi (bismuth)	(0.001)	(0.001)	(0.001)	(0.001)
Cd (cadmium)	0.002 ± 0.001	0.001	0.002 ± 0.001	0.002 ± 0.001
Ce (cerium)	0.010 ± 0.001	0.01 ± 0.002	0.01 ± 0.004	0.01 ± 0.003
Co (cobalt)	0.002 ± 0.001	0.002 ± 0.001	0.01 ± 0.006	0.003 ± 0.004
Cr (chromium)	0.18 ± 0.03	0.05 ± 0.01	0.09 ± 0.07	0.11 ± 0.07
Cs (cesium)	(0.003)	(0.003)	(0.003)	(0.003)
Cu (copper)	0.99 ± 0.48	1.02 ± 0.34	0.49 ± 0.17	0.83 ± 0.38
Fe (iron)	8.9 ± 1.7	9.15 ± 0.35	11.75 ± 2.33	9.9 ± 1.9
Ga (gallium)	0.002 ± 0.001	0.002	0.002 ± 0.001	0.002 ± 0.001
La (lanthanum)	0.007	0.003 ± 0.001	0.007 ± 0.001	0.006 ± 0.002
Li (lithium)	0.78 ± 0.25	0.6	0.6	0.66 ± 0.15
Mn (manganese)	1.45 ± 0.41	1.54 ± 0.37	1.75 ± 0.47	1.58 ± 0.35
Mo (molybdenum)	0.07 ± 0.001	0.05 ± 0.01	0.05 ± 0.01	0.056 ± 0.014
Nb (niobium)	(0.001)	(0.001)	(0.001)	(0.001)
Ni (nickel)	0.2 ± 0.1	0.01	0.40 ± 0.54	0.2 ± 0.3
Pb (lead)	0.04 ± 0.01	0.03 ± 0.002	0.14 ± 0.1	0.07 ± 0.09
Pt (platinum)	(0.001)	(0.001)	(0.001)	(0.001)
Rb (rubidium)	0.12	0.12	0.12 ± 0.01	0.12 ± 0.004
Sb (antimony)	0.01 ± 0.01	0.001	0.001	0.003 ± 0.005
Se (selenium)	(0.03)	(0.03)	(0.03)	(0.03)
Sn (tin)	0.01 ± 0.001	0.011 ± 0.005	0.004 ± 0.002	0.008 ± 0.004
Sr (strontium)	9.65 ± 0.04	9.23 ± 0.18	9.28 ± 0.62	9.39 ± 0.36
Tl (thallium)	(0.006)	(0.006)	(0.006)	(0.006)
U (uranium)	0.09 ± 0.001	0.09 ± 0.004	0.09 ± 0.01	0.09 ± 0.004
V (vanadium)	0.08 ± 0.04	0.044 ± 0.004	0.054 ± 0.011	0.06 ± 0.02
W (tungsten)	(0.001)	(0.001)	(0.001)	(0.001)
Y (yttrium)	0.007	0.007	0.008	0.007 ± 0.001
Zn (zinc)	2.96 ± 1.97	1.65 ± 0.42	1.38 ± 1.00	1.995 ± 1.26

Appendix 2. Wet weight (g) of stomach contents for Lake Trout and Arctic Charr samples from Brock Lake, 2004-2005.

Sample	Year	Stomach contents					
		Total (g)	Invertebrates (g)	Fish (g)	Unidentifiable materials (g)	Other (g)	% invertebrates
Lake Trout							
LT_1	2004	16.204	5.062	-	10.580	-	31.24
LT_2	2004	16.679	16.042	-	-	1.191	96.18
LT_3	2004	16.925	17.328	-	1.450	-	
LT_4	2004	33.127	31.118	-	2.386	-	93.94
LT_5	2004	7.810	0.800	-	6.881	-	10.24
LT_6	2004	17.587	15.850	-	1.525	-	90.12
LT_7	2004	10.051	2.022	-	6.503	1.561	20.12
LT_8	2004	11.539	11.007	-	-	1.146	95.39
LT_9	2004	16.966	10.384	-	-	2.729	61.20
LT_10	2005	9.209	0.271	-	1.385		2.94
LT_11	2005	29.432	21.919	-	4.916	-	74.47
Arctic Charr							
AC_1	2005	3.338	3.338	-	-	-	100.00
AC_2	2005	51.404	36.640	-	3.072	4.451	71.28
AC_3	2005	25.811	12.149	-	13.561	-	47.07